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THE GEOLOGY OF THE KINGLAKE DISTRICT, CENTRAL VICTORIA

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Abstract

The Siluro-Devonian sediments of the Kinglake district, Central Victoria, are described and subdivided into two formations, the rich fauna allowing correlation with other Victorian Siluro-Devonian sequences. It is shown that the vascular land plant *Baragwanathia longifolia* occurs in mudstones of Lower Devonian age, well above its hitherto accepted Lower Ludlow horizon. A lateral change in facies within the area investigated is postulated, with deeper water to the E. and N.

Petrological study indicates that the sediments were derived from both granitic and sedimentary rocks; an ancient folded and intruded terrain, contributing detritus to the Central Victorian Lower Palaeozoic trough, is envisaged. Directional sedimentary structures suggest that the sediments of the Kinglake district had a westerly source, and discussion follows on the palaeogeography of Central Victoria in Siluro-Devonian times.

The structural geology of the Kinglake district is described and a mechanism given for the genesis of the arcuate folds present. Experimental evidence indicates that this mechanism, involving basement sinistral shear-zones, would account for the arcuate fold patterns of the Silurian and Lower Devonian sediments of Central Victoria.

Finally, the petrology of the igneous rocks of the Kinglake district is briefly described.

Introduction

The rocks described in this paper occur near the W. margin of the great Central Victorian belt of Silurian and Lower Devonian sediments (Fig. 1), forming part of a complete Victorian marine sequence from the Lower Cambrian to the Lower Devonian. The sediments studied have been subjected to only one period of orogenesis, the Tabberabberan Orogeny, of late Middle or Epi-Middle Devonian time.

The area investigated is approximately 30 miles long by 20 miles wide, the S. boundary being about 15 miles N. of Melbourne. The Great Dividing Range of Central Victoria, dividing the area roughly in two, averages about 1,800 ft above sea level, and rises to 2,601 ft at Mt Disappointment. S. of the Divide is the undulating Nillumbik Terrain varying between 400 and 600 ft above sea level, while to the N. the countryside is youthfully to maturely dissected, the main streams having lower gradients than their S.-flowing counterparts.

Most exposures of rock, limited in the main to creek sections and road cuttings, were examined. Mapping was done on military contour maps, scales 1 in. to 1 mile and 2 in. to 1 mile, while air-photos proved useful in rugged country. Laboratory work was carried out at the Geology Department, University of Melbourne, where the fossils and thin sections described are lodged.

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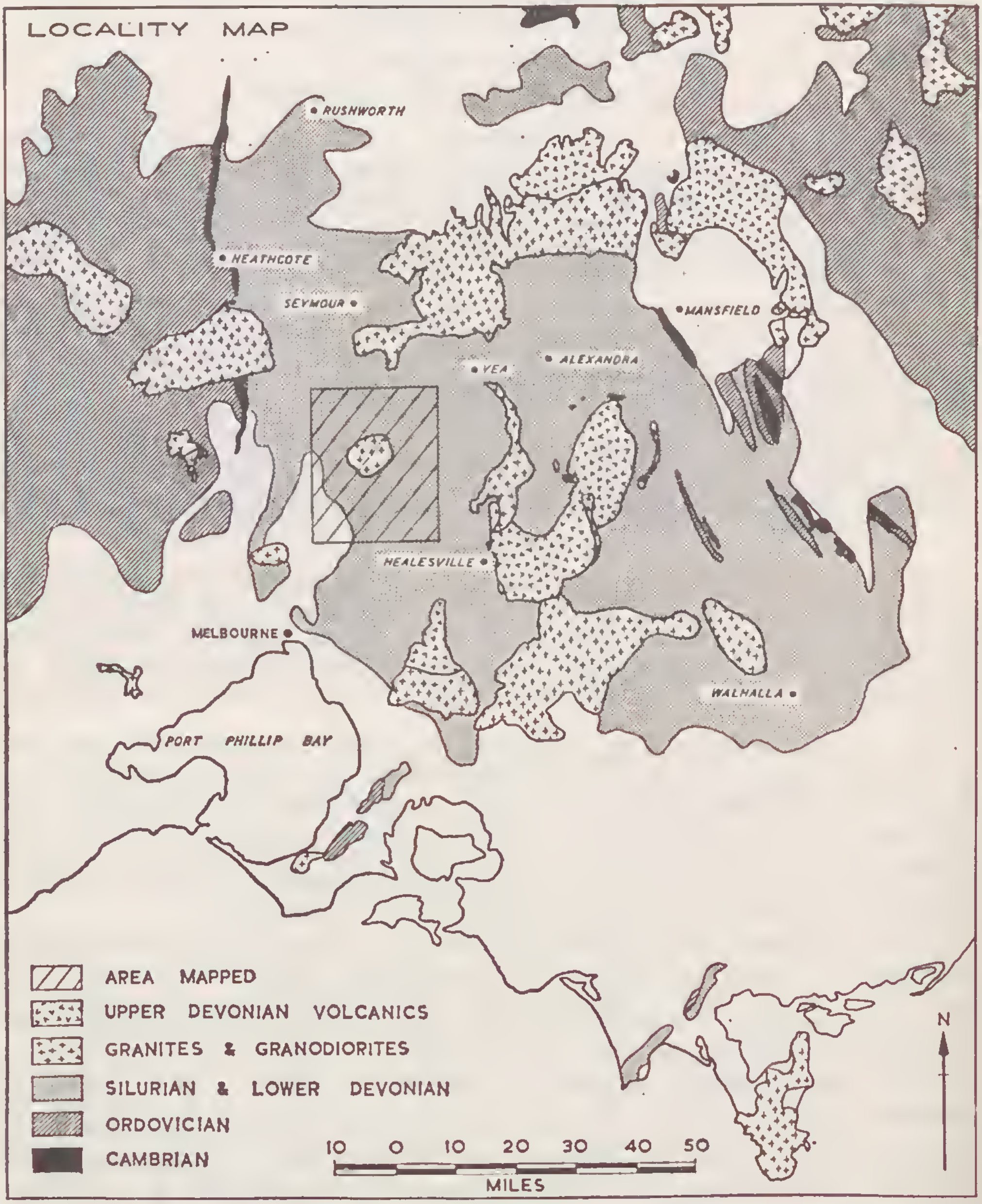


FIG. 1—Geological Map of the Lower Palaeozoic Rocks of Central Victoria.

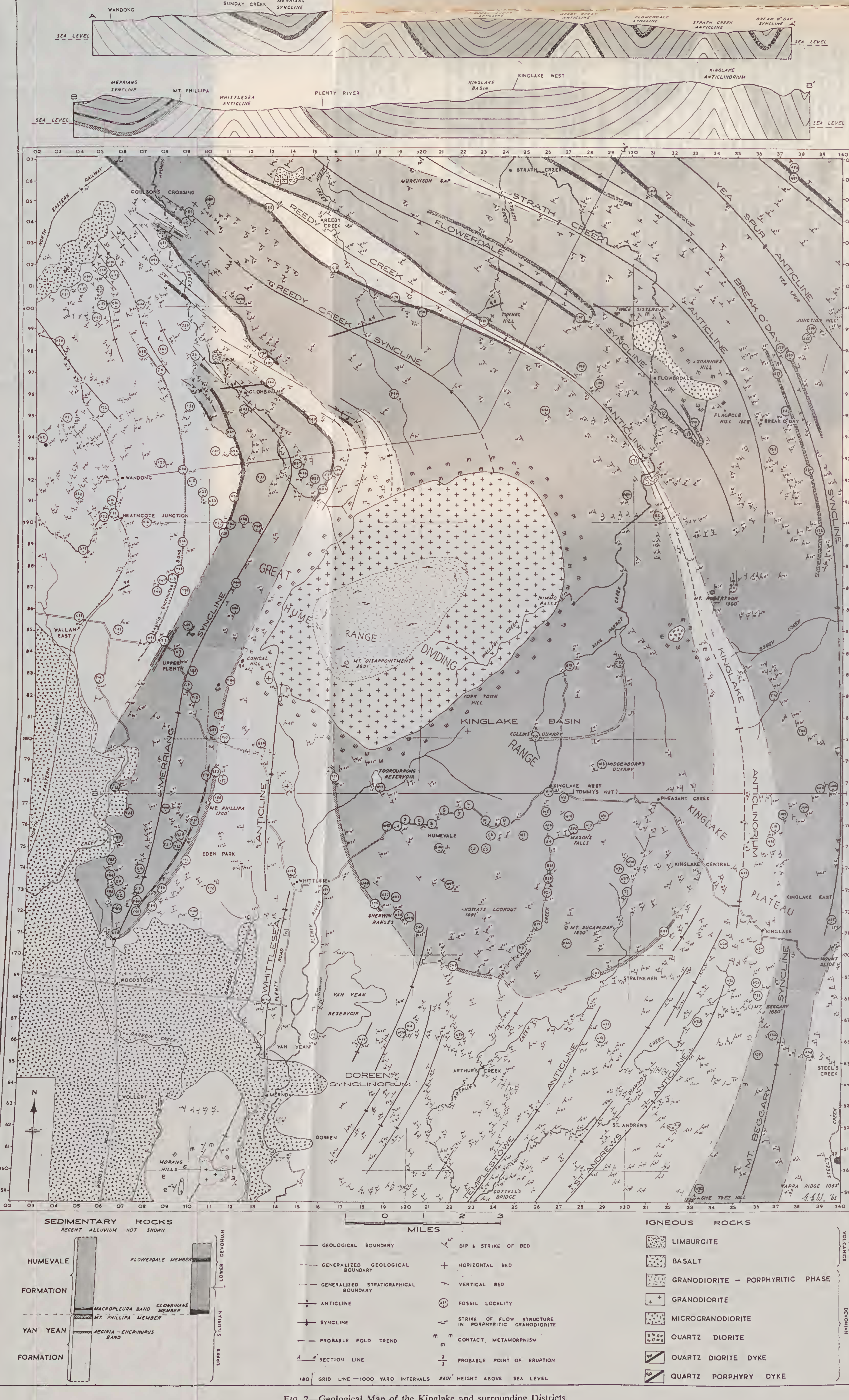


FIG. 2—Geological Map of the Kinglake and surrounding Districts.

Previous Literature

Little work had previously been done on the sedimentary rocks within the area investigated. Murray (1884) described, with map, the Reedy Ck goldfield to the NW. of Kinglake. He noted that the fold trend at Reedy Ck was at right angles to that at Melbourne, and suggested that N. of Melbourne, the folds described a curve to the W. Chapman (1904) listed fossils found near the Yan Yean Reservoir, concluding that the sediments were of Melbournian age. Jutson (1908) described the Silurian sediments at Eden Park, W. of Whittlesea, recognizing two major folds, which he named the Merriang Syncline and the Whittlesea Anticline. In an appendix, Chapman identified the fossils found by Jutson, giving a Melbournian age to the beds contained in the Whittlesea Anticline, and a Yeringian age to those in the core of the Merriang Syncline. On the basis of the chonetid brachiopod fauna, Gill (1945b) ascribed a Lower Devonian age to the siltstones at Kinglake West; further papers by Gill (1947, 1948b, 1948d) and Gill and Caster (1960) described several species of trilobites and carpoids from these beds.

Most of the igneous rocks had likewise received little attention. Whitelaw (1899) described gold-bearing dykes at Clonbinane and Steel's Ck, a further note on the gold and antimony occurrences at Clonbinane being given by Jenkins (1902). Junner (1914) included a detailed petrological study of the Yow Yow quartz diorite intrusion, Queenstown. Edwards and Baker (1944) described the petrology of the Morang Granodiorite and associated metamorphic rocks, concluding that the porphyritic phase of the intrusion was probably due to contamination by potash-rich country-rock.

Stratigraphy of the Kinglake and Surrounding Districts

The total thickness of rocks exposed is of the order of 14,000 ft, although the general monotonous lithology made subdivision difficult. The extremes of grain size are usually not great, with siltstones being by far the most common rock type present.

The sediments have been subdivided into the following two formations:

1. The Yan Yean Formation	5,000 + ft
2. The Humevale Formation	9,000 + ft

These two formations are described below in general terms. More detailed accounts of their palaeontology, petrography and sedimentary structures are given in later sections. Table 1 shows the distribution of identifiable fossils from the Kinglake district. Stratigraphical relationships are given in Table 2, while the detailed stratigraphy and structure of the area mapped is shown in Fig. 2.

THE YAN YEAN FORMATION

Age—? Middle to Upper Silurian. Estimated thickness—5,000 + ft.

The name Yan Yean Formation is proposed for strata typically exposed at Yan Yean, S. of Whittlesea, and also developed in the Wandong, Clonbinane and Kinglake East districts, the formation consisting of rhythmically bedded sandstones and mudstones in the type area. This formation, the base of which is not seen, is conformably overlain by the Humevale Formation, and its development in a number of districts is discussed below.

YAN YEAN DISTRICT

The maximum thickness exposed here is approximately 5,000 ft on the flanks of the Whittlesea Anticline, the sediments being evenly-bedded, and often laminated sandstones, mudstones and siltstones (Pl. XLVII, fig. 1). The sandstones, generally a pale yellow-brown, often exhibit cross-bedding, ripple-drift bedding, and flute casts. Grading is occasionally present in these beds, but only within the range of sand-size particles. The mudstones and siltstones, mainly light blue-grey to brown in colour, often contain fine sandstone laminae which may become impregnated with iron oxide and stand out as thin bands on weathering. Several large slump structures are present, the mudstones being greatly contorted between the competent sandstone strata.

The sediments are poorly fossiliferous, with most of the fossils occurring sporadically in the mudstones. At the Yan Yean Reservoir dark mudstones contain a distinctive fauna of numerous *Encrinurus* sp. and *Aegiria* sp.; N. of Whittlesea is a band containing abundant monograptids.

An assemblage of micaceous sandstones is taken to represent the top of the Yan Yean Formation at Eden Park and Whittlesea. The sandstones are symmetrically developed on each side of the Whittlesea Anticline, and were first noted as a possible marker horizon by Jutson (1908). The beds, containing numerous *Nucleospira* sp. and small rhynchonellids, are important because they show the relative ages of the fossiliferous siltstones at Eden Park and Kinglake West. Being typically developed at Mt Phillipa, W. of Whittlesea, the sandstones are named the Mt Phillipa Member.

The sediments of the Yan Yean district have been thrown into a number of N.-S.-trending folds. Dips from 40° to 70° are common, with occasional vertical beds and crush-zones, although none of the mudstones has been converted into slate.

UPPER PLENTY DISTRICT

At Upper Plenty about 4,000 ft of easterly-dipping sandstones and siltstones are developed. The lower 2,000 ft, predominantly siltstones, have produced several specimens of *Dalmanites wandongensis* Gill. The upper beds contain poorly preserved graptolites, while a mudstone band containing *Encrinurus* sp. and *Aegiria* sp. has been traced N. for about 6 miles to the Wandong district. This band is probably on the same horizon as the *Encrinurus-Aegiria* beds at Yan Yean. The top of the formation is marked by sandstones containing abundant small rhynchonellids, almost certainly equivalent to the Mt Phillipa Member.

WANDONG DISTRICT

In the Heathcote Junction-Wandong district, the Yan Yean Formation is represented by over 5,000 ft of tightly folded mudstones, siltstones and occasional sandstones.

The lower 2,000 ft in the Heathcote Junction district are similar lithologically to the rocks at Yan Yean, and contain few fossils. S. of Bald Hills, at Locality F31, a sandstone horizon above these lower beds contains an abundant fauna, noteworthy for the great number of starfish, carpoids and graptolites. This is Locality Bb23, Quarter Sheet No. 4 NW., of the Geological Survey of Victoria.

About 2,000 ft of rhythmically-bedded siltstones and very thin ripple-bedded sandstones follow, typically developed at Broadhurst's Ck and the Wandong railway quarries. At the Wandong quarries the beds are low-dipping as they occur in the centre of a NW.-plunging syncline, and are characterized by the presence of

Dalmanites wandongensis Gill, locally abundant. It is considered that these siltstones are in part equivalent to the lower beds at Upper Plenty.

The upper 1,000 ft of the Yan Yean Formation are composed of siltstones and sandstones containing *Encrinurus* sp. and *Phacops* sp., the abundance of *Encrinurus* suggesting part equivalence with the *Encrinurus* beds at Upper Plenty and the Yan Yean Reservoir.

OTHER DISTRICTS

Siltstones and sandstones stratigraphically equivalent to the Yan Yean Formation are present in the crests of the major anticlines at Reedy Ck and Kinglake, but have proven poorly fossiliferous. However, at locality Y73 about 2 miles S. of Flowerdale, mudstones contain numerous *Encrinurus* sp. and small rhynchonellids.

THE HUMEVALE FORMATION

Age—Upper Silurian to Lower Devonian. Estimated thickness—8,500-9,000 ft.

The name Humevale Formation is proposed for the great thickness of siltstones, and rare sandstones and conglomerate conformably overlying the Yan Yean Formation. Massive siltstones comprise most of the formation, and are typically exposed at Humevale, about 3 miles SW. of Tommy's Hut. The formation is extremely widespread, being developed at Eden Park, Kinglake West, the Clonbinane-Flowerdale-Yea district, and W. of Steel's Ck.

Two arenaceous members are recognized in the Humevale Formation, the Clonbinane Member at the base and the Flowerdale Member near the top. The siltstones forming the greater part of the formation will be referred to as the Humevale siltstones.

THE CLONBINANE MEMBER

Maximum thickness—400 ft; average thickness—200 ft.

The Clonbinane Member is composed mainly of yellow-brown micaceous sandstones typically exposed in cuttings along Spur Rd and Quarry Rd, Clonbinane. The sandstones are medium to fine-grained, averaging about 1 ft to 18 in. in thickness (Pl. XLVII, fig. 2). They are often well laminated, and occasionally show graded bedding with mud-pellets along the base of some beds, cross-bedding, ripple-drift bedding, and flute casts. Fossils are locally abundant in narrow bands. Interbedded blue-grey siltstones and mudstones are generally only a few inches thick, having either a sharp or a gradational contact with the underlying sandstones.

The member outcrops within about 200 square miles in the NW. of the area mapped, with both grain size of the sandstones and thickness of the member increasing to the NW. S. and E. of Clonbinane the relative proportion of interbedded siltstones increases until the sandstones are no longer mappable. Thus the Clonbinane Member may be regarded as lenticular, wedging out to the S. and E. Near Broadford to the NW., the rock has been quarried for building material, and is known locally as 'Broadford stone'.

The Clonbinane Member is moderately to steeply dipping, averaging about 50°-60°. The beds are repeated five times from W. to E. by the major folding, and generally strike NW., although S. of Clonbinane the trend is NNE. Crush zones are present at Tunnel Hill and Coulson's Crossing, while auriferous quartz veins and unmineralized joints are widespread. The sandstones often form prominent strike ridges, such helping greatly in their mapping.

THE HUMEVALE SILTSTONES

Estimated thickness—8,500 ft.

These beds are extremely widespread and form the bulk of the sediments of the Humevale Formation. The conglomerates and grits of the Flowerdale Member are interbedded with these siltstones high in the sequence.

The lithology is very monotonous, the beds at Kinglake West being fine-grained siltstones and mudstones from 2 ft to 8 ft thick (Pl. XLVII, fig. 3), with a few interbedded sandstones. The siltstones are dark blue-black in colour when fresh, weathering to a grey or yellowish-brown. Sedimentary structures are rare, cross-bedding occurring in only the coarser-grained strata.

HUMEVALE-KINGLAKE WEST

The siltstones at Kinglake West form a broad synclinal structure, with most beds dipping about 10° N. The sequence has been divided into four, each division representing about 2,000 ft of sediments.

Lower 2,000 ft:

These beds directly overlie the sandstones of the Mt Phillipa Member and are poorly fossiliferous, with shelly fossils occurring sporadically in the thick siltstones.

2,000-4,000 ft:

Here fossils begin to be more plentiful with the entry of many new species, although there is no change in lithology. Characteristic forms are *Notanoplia australis* (Gill) and *Chonetes ruddockensis* Gill.

4,000-6,000 ft:

Exposure is poor, but the few fossil localities have produced an abundant fauna.

Middendorp's Quarry, on Stony Ck, about 1½ miles NE. of Tommy's Hut, lies a few hundred feet above the base of this division. Gill (1947) recognized three main fossiliferous bands at this locality, one rich in trilobites, one in corals, and the third containing mainly echinoderms. The lithologies of the bands are similar, being blue to grey fine-grained siltstones with a few thin current-bedded sandstones. Due to the poor exposure, these fossiliferous bands have not been traced further in the field.

Nearly 1,000 ft above the Middendorp's Quarry horizon are the sandstones and siltstones of Collins's Quarry, at the headwaters of King Parrot Ck. The sandstones are yellow to grey in colour, show graded bedding, occasional crossbedding and contain an abundant fauna. They have been traced to the N. and E. in Stony Ck and Mathieson's Ck, but poor exposure did not permit their total thickness to be calculated.

6,000 ft to top of sequence:

There is little change in lithology to the top of the sequence, although the siltstones generally are not as fossiliferous as those of the previous division. The top of the Humevale Formation is not seen, the upper beds having been intruded by the Mt Disappointment Granodiorite.

EDEN PARK-UPPER PLENTY

At Eden Park, W. of Whittlesea, about 3,000 ft of coarse siltstones and fine sandstones overlie the Mt Phillipa Member in the Merriang Syncline, and are considered equivalent to the lower 3,000 ft of the Humevale Formation at Humevale-Kinglake West.

0-2,000 ft:

These beds are coarser-grained and contain a much more abundant fauna than equivalent strata at Humevale. The lowest fossiliferous beds occur about 400 ft above the base of the Humevale Formation, and belong to the 4 ft thick 'limestone band' of Jutson (1908). This band contains an abundant brachiopod fauna, and at Cemetery Lane much of the original calcareous material of the shells is preserved. The band is characterized by a large spiriferid, *Macropleura densilineata* (Chapman), and has been traced from Cemetery Lane for over 4 miles to the N., also being found on the W. limb of the syncline at Upper Plenty. However, in the N. outcrops the calcareous material has been leached away, leaving the impressions of the fossils in the silty matrix. The *Macropleura* Band, shown in Fig. 2, is considered to be on a similar horizon to the Clonbinane Member outcropping to the N.; brachiopod faunas are comparable, although the Clonbinane Member is relatively richer in echinoderms, and the *Macropleura* Band in trilobites. This is probably a reflection of facies.

Except for *Macropleura*, similar fossils to those of the *Macropleura* Band are found in the remaining 1,600 ft of this division.

2,000-3,000 ft:

The top 1,000 ft are contained in the core of the Merriang Syncline at Upper Plenty. The lithology is slightly different from the lower beds at Eden Park, with the thick, indurated siltstones gradually giving way to thinner bedded siltstones, mudstones and occasional sandstones. There is also a change in fauna, with the presence of *Notanoplia, Plectodonta*, and *Chonetes ruddockensis* further emphasizing the equivalence of these beds with those of the second lowest division at Kinglake West.

CLONBINANE-FLOWERDALE-YEA

Over 6,000 ft of siltstone in beds 6 in. to 18 in. thick overlies the sandstones of the Clonbinane Member in the major synclines of the Clonbinane-Flowerdale-Yea district, being interbedded with the conglomerate of the Flowerdale Member near the top of the sequence.

0-2,000 ft:

These beds are generally poorly fossiliferous, but have yielded a single specimen of *Monograptus dubius* cf. *thuringicus* Jaeger only a few hundred feet above the top of the Clonbinane Member, and *M.* cf. *uncinatus* at Break-o'-Day.

2,000-4,000 ft:

Probably equivalent to the second lowest division at Kinglake West, and the upper beds at Eden Park.

4,000-6,000 ft:

The horizon of the Flowerdale Member is taken as the top of this division. These upper beds, now represented by slates, occur near the axes of the major synclines. The cleavage is rarely parallel to the bedding and consequently no fossils have been found in these beds, which appear to be slightly finer-grained than the underlying siltstones. However, the cleavage decreases in intensity to the E., and numerous fossils, notably *Baragwanathia longifolia* Lang and Cookson and *Panenka* sp., have been found in fine siltstones in a road-cutting about 4 miles SW. of Yea (Locality A82). As this locality underlies the Flowerdale Member by only about 200 ft, it is considered to be on approximately the same horizon as Collins's Quarry at Kinglake West.

Siltstones above the Flowerdale Member show intense cleavage, and so far have not yielded any fossils.

STEEL'S CK-KINGLAKE EAST

A large syncline running from W. of Steel's Ck through Kinglake East and N. towards Break-o'-Day contains approximately 6,000 ft of siltstones and mudstones, most referable to the Humevale Formation, although absence of marker horizons makes exact correlation difficult.

W. of Steel's Ck, fine blue-grey siltstones and occasional sandstones have yielded a small fauna. At Kinglake East the beds are finer grained and less fossiliferous than those at Kinglake West. It was not possible to mark an exact boundary here between the Yan Yean and Humevale Formations, but the lowest fossil localities (L109, L111) are probably on approximately the same horizon as the Mt Phillipa Member of the Yan Yean Formation. The upper 3,000 ft of siltstones and mudstones contain a similar fauna to the upper 3,000 ft at Kinglake West.

THE FLOWERDALE MEMBER

Maximum thickness—approximately 200 ft.

The Flowerdale Member consists of a persistent horizon of conglomerate, grits and sandstones present in the cores of three major synclines in the Flowerdale-Yea district, although not developed in beds of equivalent age at Kinglake West. However, this member is considered to be on a similar horizon to the sandy beds at Collins's Quarry, Kinglake West (see Table 2).

The Flowerdale Member has been divided into two lithological units, a lower conglomerate phase, and an upper sandstone-grit phase.

Conglomerate Phase: Maximum thickness—50 ft.

The conglomerate is not as extensive as the grits and sandstones, but where present, almost invariably forms the base of the member, except where locally underlain by a few feet of coarse sandstone. The pebbles, mainly of reef quartz and quartzite, and occasionally slate, chert and sandstone, range in size from a fraction of an inch to 1 ft in diameter, in most cases being poorly sorted. The great majority are well-rounded, although the smaller ones of less than an inch diameter are often angular or only slightly worn (Pl. XLVIII, fig. 1). The matrix of the conglomerate varies in texture from fine siltstone to coarse sandstone, much of the siltstone now being represented by slate. The largest pebbles occur at Locality Y97 in the SW.

Abundant crinoid columnals and small, poorly preserved brachiopods are ubiquitous in the conglomerate, but at localities Y97 and A85 numerous well-preserved fossils are present in the muddy matrix, many of the species not having been found elsewhere in the Kinglake district. These two widely spaced localitis with similar faunas suggest equivalence of all outcrops of conglomerate within the area investigated.

Sandstone-Grit Phase: Average thickness—100-150 ft.

This phase overlies the conglomerate and locally comprises the whole of the Flowerdale Member. The sandstones and grits, of grey to light-brown colour, occur in beds 1 to 3 ft thick often containing small quartz pebbles and calcareous shell fragments. Graded beds and flute casts are common, although cross-bedding is not well developed. Fossils are numerous and comparable with those from the upper beds at Kinglake West.

TABLE 1

Distribution of Fossils from the Kinglake and surrounding Districts

SPECIES	YAN YEAN FORMATION							HUMEVALE FORMATION														
	Yan Yean	Upper Plenty		Wandong District				Clonbinane Member	Kinglake West					Eden Park		Clonbinane-Flowerdale-Yea			Steel's Creek	Kinglake East	Flowerdale Member	
											4,000′–6,000′											
		0–2,000′	2,000′–4,000′	0–2,000′	F31	2,000–4,000′	4,000′–5,000′		0–2,000′	2,000–4,000″	Midd. Q.	Coll. Q.	6,000′→	0–2,000′	2,000′–3,000′	0–2,000′	2,000′–4,000′	4,000′–6,000′			Conglomerate	Sandstone
Tabulata																						
Pleurodictyum megastoma McCoy								c		c	c	c		c	c	r	o		r		c	c
P. sp.								c	r	c	c	c	o		c						o	
Favosites cf. *forbesi* Edwards and Haime																					r	
F. sp.								r			o	o									o	
Rugosa																						
'*Lindstroemia*' *scalaris* Chapman	r				o								r							r		
'*L.*' *parva* Chapman	r	r					o													r		
'*L.*' *conspicua* Chapman	r	r					o	o	r	o				c	c		o					
'*L.*' *yeringae* Chapman										o	c	c	o									
'*L.*' *ampla* Chapman										o	c	c								r		o
Rhizophyllum sp.																					o	
cf. *Syringaxon*																					o	
Annelida																						
Keilorites sp.	o	r				r		o	r	o			r			r			r			
Polyzoa																						
Fenestella sp.												o									o	o
Polyzoa indet.					c			c	o					c	o							
Brachiopoda																						
Chonetes melbournensis Chapman	r																					
C. ruddockensis Gill										o	o	o	r		c		r			o		r
C. cresswelli Chapman											o	o										r
C. cf. *psiloplia* Gill										r									r			
C. sp. nov.										r						r						
Macropleura densilineata (Chapman)														c								
Eospirifer aff. *togatus* (Barrande)																					c	
Howellella sp.								o			o	c									o	o
Nucleospira sp.	o	r			a		o	c	o	o	o	o				r			r			
Isorthis sp.								a		o	o			a	c				c			
I. festiva Philip																					r	
Tyersella sp.																					r	
Dalmanellids indet.		r	o				o	a	o	o			r	a	c	o			c	o	c	
Leptaena '*rhomboidalis*' (Wilckens)														a								
L. sp.								o		o	o									r	o	
Notoleptaena sp.										o	o						r					r
Leptostrophia sp.								o						c	o					r	o	o
Atrypa '*reticularis*' (Linnaeus)								c						a								
Lissatrypa sp.								o				o		o						o	o	
L. lenticulata Philip									o	c	c											o
Notanoplia australis (Gill)										c	c	c	o		c		o			o	o	c
N. withersi (Gill)										o	c	o										o
Plectodonta bipartita (Chapman)								r	r	o	c		o		c	r	o		o	o		o
Aegiria sp.	o		c	r	o		o															
Stegerhynchus sp.			c		c			a	o	o				a	c				c			
Rhynchonellids indet.	c		c		c		c	a	o			c		a	c	o			c	c		
Notoconchidium sp.															o							
Lingula sp.	r						o	o		o	o	o		o			r					
Lamellibranchiata																						
Ctenodonta sp.	r	r							r	c	o		o	o	c					o		
Nuculites sp.	r	r					o							o	o							
N. maccoyianus Chapman									r	o	o									r	o	
Panenka sp.																		o				
Actinopteria boydi (Conrad)								r						o								
cf. *Parallelodon*																				r		
cf. *Lunulicardium*													r							r		
Gastropoda																						
Bellerophon sp.										o		o		o			r					
Straparollus sp.								o									r				o	
Loxonema sp											o										o	
cf. *Platyceras*										r												
Cephalopoda																						
Orthoceracones indet.	r	r		r					r	r		o			r	r		o				
Mollusca Incertae Sedis																						
Hyolithes sp.	r	o		o		o			r	c	o	o	o		o		o			o		
Crinoidea																						
Crinoids spp. nov.				r	c			c				c							r			
Crinoid columnals	o	o	o		a	o	o	a	o	c	o	a	o	c	o	r	o		o	o	a	a
Carpoidea																						
Victoriacystis aff. *wilkinsi* Gill and Caster											r											
Rutroclypeus victoriae Gill and Caster											r											
R. junori Withers											r	r										
R. ? *withersi* Gill and Caster											r											
Carpoids spp. nov.					o			o														
Blastoidea																						
Blastoids spp. nov.											r	r										
Cystoidea																						
Cystoids spp. nov.											r	r										
Asteroidia																						
Lepidaster australis (Withers and Keble)	r																					
Phillipsaster selwyni (McCoy)					c		o	o														
Ulrichaster biradialis (Withers and Keble)					c																	
Schuchertia junori Withers and Keble												o										
Petraster sp.											r											
Asteroids spp. nov.					c		o	o			r											
Ophiuroidia																						
Lapworthura miltoni (Salter)								o			r	o										
L. pulcherrima Withers and Keble								o														
Furcaster kilmorensis Withers and Keble								o														
Crepidosoma kinglakensis Withers and Keble												c								r		
Urosoma parvus (Withers and Keble)												c										
Eospondylus cf. *tenuis* Withers and Keble												o										
Sturtzura sp.											r											
Ophiuroids spp. nov.	r				c			o			r											
Graptolithina																						
Monograptus colonus	o																					
M. chimaera var. *salweyi* (Barrande)				r	c																	
M. bohemicus (Barrande)	r																					
M. dubius? (Suess)	r		r	r																		
M. dubius cf. *thuringicus* Jaeger																r						
M. varians var. *pumilus* Wood					o																	
M. '*uncinatus*'																r						
Trilobita																						
Encrinurus sp.	o		c		o		a															
Otarion sp.											r	r		o								
Ampyx yarraensis Chapman	r																					
Dalmanites sp.	r						o															
D. wandongensis Gill		o				c																
Odontochile sp.								r	r			r		c		o						r
O. formosa Gill										c	c						r			r		
Phacops sp.	r								r	c	c	r		c							o	
P. cf. *crossleii* Etheridge fil. and Mitchell							o															
Proetus euryceps (McCoy)											o											
Calymene sp.										o				o						r	o	
C. bowiei Gill			r																			
Gravicalymene angustior (Chapman)												o										o
Trimerus vomer (Chapman)						r																
T. kinglakensis Gill											c											
cf. *T. lilydalensis* Gill																	r					
Homalonotids					r									c	c							
Dicranurus kinglakensis Gill											o	r										
Scutellum sp.											r											
Ostracoda																						
Beyrichiacea	r				r	r	r		r	r	o	r	r							r		r
Phylum Incertae Sedis																						
Conularia sp.						r	r		r	r		r		r						r		
Plantae																						
Baragwanathia longifolia Lang and Cookson																		c				
Hostimella sp.																		o				a
cf. *Psilophyton*																		o				
Plant fragments indet.											c	c								c		a

a = abundant; c = common; o = occasional; r = rare.

Palaeontology

The main groups of organisms are reviewed, emphasis being placed on local stratigraphical use. However, many species remain unidentified.

TABULATE CORALS

Only two genera of tabulate corals, *Pleurodictyum* and *Favosites*, have been identified, both being restricted to the Humevale Formation. *Pleurodictyum megastoma* McCoy is common in the Clonbinane Member, and also in the lower beds of the Humevale Formation at Eden Park, although here the average cell diameter is smaller than most specimens from the Clonbinane Member. *P. megastoma* becomes abundant in the upper beds at Kinglake West where it attains its greatest corallite diameter, thus confirming Philip's (1962) observation that the diameter tends to increase at progressively younger horizons. However, facies seems also to exercise some control in this respect. The small-celled species of *Pleurodictyum* generally has a similar distribution to that of *P. megastoma*, although absent from the lower beds at Eden Park. The tabulate corals are almost invariably associated with an abundant shelly fauna, suggesting they preferred a shallow water environment.

RUGOSE CORALS

Rugose corals are widely distributed, most being referable to species of '*Lindstroemia*' (Chapman 1924). *L. parva* Chapman and *L. scalaris* Chapman, the two smallest forms, are almost entirely restricted to the Yan Yean Formation, occurring sporadically in the mudstone. *L. conspicua* Chapman, of moderate size up to 15 mm long, is common in the siltstones of the Yan Yean Formation in the Wandong district and the lower beds of the Humevale Formation at Eden Park, but rare at higher horizons. The largest forms, *L. yeringae* and *L. ampla*, attain a length of 20 mm and 25 mm respectively, being common in the upper beds at Kinglake West.

The conglomerate phase of the Flowerdale Member contains a distinctive rugose coral fauna, with *Rhizophyllum* sp., *Syringaxon* sp. and Rugosa indet. being similar to forms described by Talent (1959) from E. Victoria.

ANNELIDS

Worm tunnels and tracks, some referable to the genus *Keilorites*, occur occasionally in the siltstones. Gill plumes are rare, being found only in the shales interbedded with the sandstones of the Clonbinane Member.

POLYZOA

Small trepostome and cyclostome polyzoa occur throughout the sequence, although they have not proven of stratigraphical value. *Fenestella* sp. is restricted to the sandstones of the Collins's Quarry horizon, Kinglake West, and the Flowerdale Member.

BRACHIOPODS

Brachiopods are by far the most abundant fossils, occurring in all lithologies from mudstone to conglomerate.

Chonetids are stratigraphically useful, with *Chonetes melbournensis* Chapman being restricted to the Yan Yean Formation, while *C. ruddockensis* Gill, *C. cresswelli* Chapman, *C.* cf. *psiloplia* Gill, and a number of new species of *Chonetes* are found only in the middle to upper beds of the Humevale Formation.

Macropleura densilineata (Chapman) has a very restricted range, being found only at Eden Park-Upper Plenty, and it is likely that its distribution has been controlled by facies. Similarly, *Eospirifer* aff. *togatus* (Barrande) occurs only in the conglomerate phase of the Flowerdale Member.

Atrypa 'recticularis' (Linnaeus), although having a wide range elsewhere in Victoria, is here restricted to the Clonbinane Member and the lower beds at Eden Park. *Lissatrypa lenticulata* Philip and *Plectodonta bipartita* (Chapman) enter at the base of the Humevale Formation, although both species become more common higher in the sequence. *Aegiria* sp., similar to *Plectodonta bipartita* but lacking the strong median septa, is almost entirely restricted to the *Aegiria-Encrinurus* Band high in the Yan Yean Formation.

Notanoplia australis (Gill) and *N. withersi* (Gill) do not enter till the second lowest division of the Humevale Formation, being most common in the upper beds at Kinglake West where they are associated with *Lissatrypa, Plectodonta* and *Chonetes*.

Isorthis sp. is abundant with other dalmanellids in the lower beds at Eden Park and the Clonbinane Member. Dalmanellids are not common higher in the sequence at Kinglake West, although in the conglomerate of the Flowerdale Member *Isorthis festiva* Philip and *Tyersella* sp. have been identified.

Leptaena 'rhomboidalis' (Wilckens) is characteristic of the lower beds at Eden Park, while leptaenids are found occasionally throughout the whole of the Humevale Formation. *Leptostrophia* sp. first appears in the Clonbinane Member, being quite common at Eden Park and in the Flowerdale Member. No doubt a number of different species of this genus are represented.

'Camarotoechia decemplicata', now identified as *Stegerhynchus* sp. (Dr J. Talent pers. com.) is common with numerous poorly preserved rhynchonellids in the upper beds of the Yan Yean Formation, and continues into the lower portion of the Humevale Formation. Two specimens of *Notoconchidium* sp. have been found at Locality F12, Upper Plenty.

Lamellibranchs

Most forms are long ranging and of little use stratigraphically. *Actinopteria boydi* (Conrad) is restricted to the Clonbinane Member and the lower beds at Eden Park, while specimens comparable with *Parallelodon* and *Lunulicardium* have been found in the fine mudstones at Kinglake East, these two genera being common in the rocks of the Warburton area. *Panenka* sp. showing fine radial striations occurs in mudstones high in the Humevale Formation at Locality A82, in the NE. corner of the area mapped.

Gastropods

Gastropods occur sporadically throughout the entire sequence. The doubtful gastropod *Hyolithes* is most common, and several species appear to be present.

Cephalopods

Fragments of orthoceracones are found occasionally in the mudstones and siltstones, consistent with their probable pelagic existence.

Crinoids

Crinoid columnals are extremely common, although complete crinoids are almost entirely restricted to the sandstones and associated with an abundant shelly fauna. Specimens from Locality F31, Yan Yean Formation; the Clonbinane Member; and Collins's Quarry, Kinglake West, show beautiful preservation, but have not been studied in detail.

CARPOIDS

Four species of carpoid from Collins's and Middendorp's Quarries, Kinglake West, have been described by Gill and Caster (1960). Several new genera found at Locality F31 and in the Clonbinane Member were given to Mr E. D. Gill of the National Museum, Melbourne.

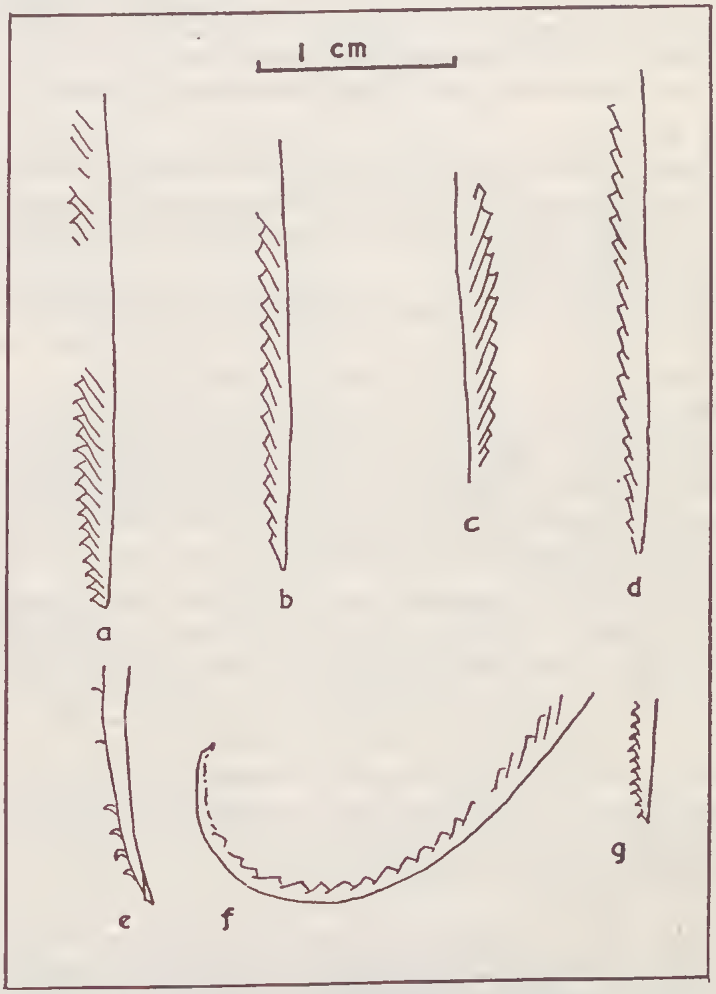


FIG. 3—Graptolites from the Kinglake and surrounding districts:
- a. *Monograptus colonus*, Locality D143
- b. *M. dubius* ? (Suess), Locality D140
- c. *M. dubius* ? (Suess), Locality H87
- d. *M.* cf. *dubius thuringicus* Jaeger, Locality X50
- e. *M.* sp. indet., Locality E56
- f. *M. bohemicus* (Barrande), Locality F10
- g. *M. varians* var. *pumilis* Wood, Locality F31

BLASTOIDS AND CYSTOIDS

Blastoids and cystoids are very rare, only fragmentary remains having been found at Middendorp's and Collins's Quarries, Kinglake West.

ASTEROIDS AND OPHIUROIDS

As with the crinoids, asteroids and ophiuroids are restricted to the sandstones, being most common in the Clonbinane Member, Locality F31, and Collins's Quarry, Kinglake West. It thus seems that most enchinoderms preferred a clear-water environment. The Collins's Quarry horizon is characterized by *Crepidosoma kinglakensis* Withers and Keble and *Urosoma parvus* (Withers and Keble). Several of the generic names for the starfish and brittlestars given by Withers and Keble (1933, 1934) have been altered according to suggestions by Spencer (1950).

GRAPTOLITES

Although rare, graptolites are by far the most useful fossils stratigraphically. They are almost entirely restricted to the mudstones, and rarely were more than one or two specimens found at the one locality. The better-preserved graptolites, shown in Fig. 3, include the following:

Monograptus colonus (Fig. 3a), at Locality D143 in mudstones of the Yan Yan Yean Formation, 141,737 Yan Yean Military Map.

Monograptus varians var. *pumilus* Wood (Fig. 3g), common at Locality F31, Yan Yean Formation, 033,008 Kinglake Military Map.

Monograptus bohemicus (Barrande) (Fig. 3f) at Locality F10 in mudstones of the Yan Yean Formation, 109,798 Kinglake Military Map.

Monograptus dubius ? (Suess) (Fig. 3b & c) at Locality Q2, Broadhurst's Ck, 023,937 Lancefield Military Map; Locality D140, 133,678 Yan Yean Military Map; Locality H87, 077,028 Kinglake Military Map; Locality G39, Heathcote Junction, 044,887 Kinglake Military Map; all localities in the Yan Yean Formation.

Monograptus dubius cf. *thuringicus* Jaeger (Fig. 3d), found singly in siltstones of the Humevale Formation, Locality X50, Stony Ck, 090,043 Kinglake Military Map, a few hundred ft above the top of the Clonbinane Member.

Monograptus sp. (Fig. 3e). Several incomplete specimens were found in mudstones low in the Humevale Formation W. of Junction Hill, Locality E56, 384,989 Glenburn Military Map. The hooked thecae, long sicular and broken-backed appearance suggest *Monograptus uncinatus* var. *orbatus* Wood. However, many Upper Ludlow graptolites show proximal thecae of the '*uncinatus*' type (Jaeger 1959), so no definite identification can be given in the absence of a complete specimen.

TRILOBITES

Trilobites are widely distributed throughout the mudstones and siltstones of both formations, although rare in the sandstones, indicating their preference for a muddy sea floor. Complete specimens are rare, the most common fragments being pygidia and to a lesser extent cephalons.

Encrinurus sp. is a characteristic fossil of the Yan Yean Formation, being most common in the upper beds where it forms a mappable horizon with the brachiopod *Aegiria*.

Dalmanitid trilobites are abundant and the most useful stratigraphically. *Dalmanites wandongensis* Gill is found only within the Yan Yean Formation in the siltstones at Wandong and Upper Plenty. *Odontochile* sp. enters at the base of the Humevale Formation, being most common in the beds at Eden Park. Here, all dalmanitids with 16 or more pygorachial segments have been classified as *Odontochile*, hypostomes not being available for study. *Odontochile formosa* Gill enters in the second lowest division of the Humevale Formation at Kinglake West. Thus, Gill's (1948d) sequence, *Dalmanites wandongensis* → *Odontochile meridianus* → *Odontochile formosa* is in part confirmed.

Phacopiid trilobites are common but of little use stratigraphically, with the possible exception of *Phacops* cf. *crossleii* Etheridge fil. and Mitchell, which appears to be restricted to the upper beds of the Yan Yean Formation. Calymenids are not common, with *Gravicalymene angustior* (Chapman) being found mainly in the Collins's Quarry horizon, Kinglake West, and the Flowerdale Member.

Homalonotid trilobites are not widespread although common locally. *Trimerus vomer* (Chapman) occurs at Wandong in siltstones of the Yan Yean Formation, while *Trimerus kinglakensis* Gill has been found only at Middendorp's Quarry, Kinglake West, thus supporting Gill's (1948b, p. 72) opinion 'that *T. kinglakensis* is genetically related to, and probably a little later in time than, *T. vomer*'. Poorly preserved homalonotids common in the lower beds at Eden Park do not appear to be referable to either of the above species. A single pygidium similar to that of *Trimerus lilydalensis* Gill was found at Locality F41, Clonbinane, in siltstones of the Humevale Formation.

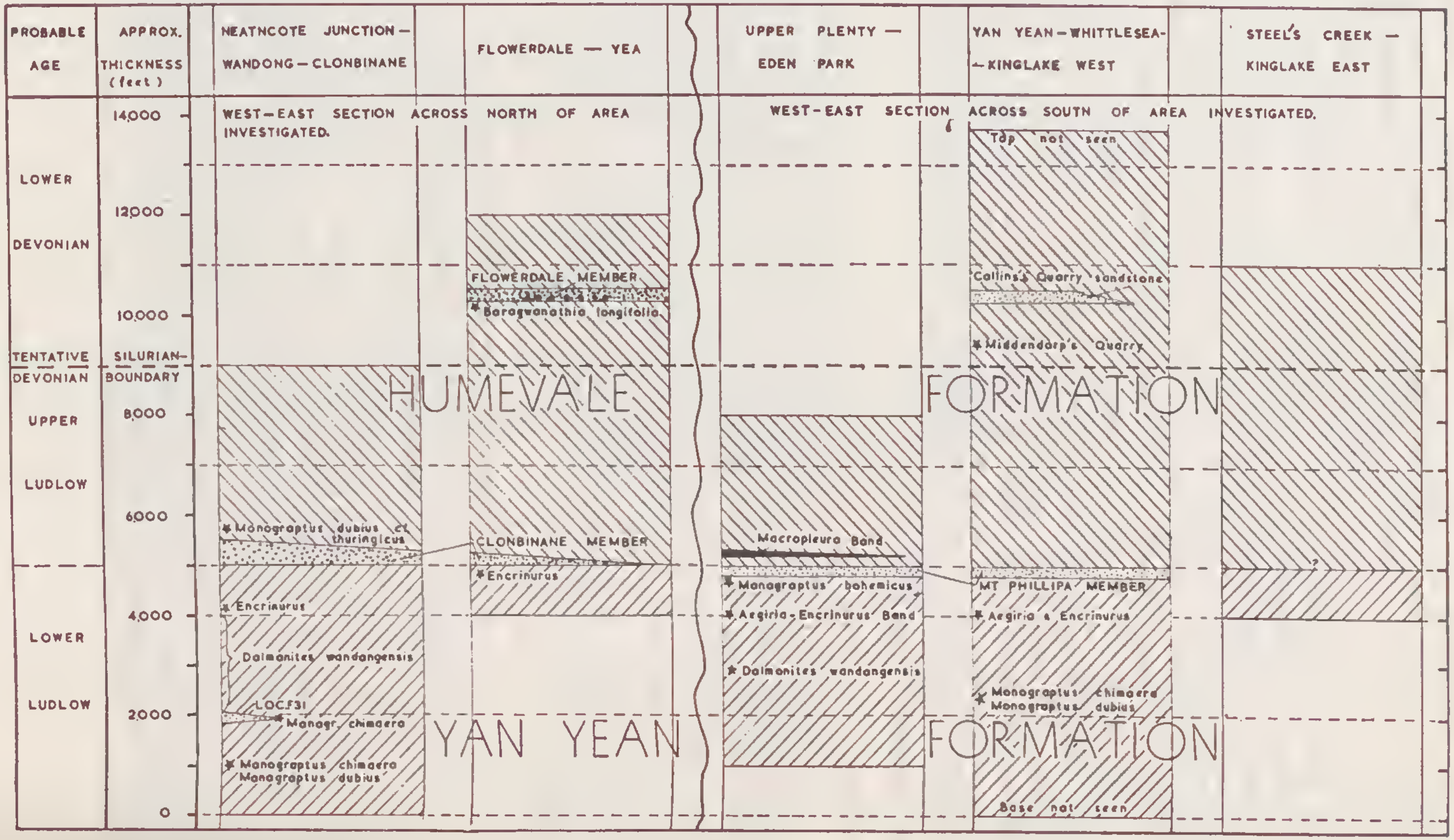
PLANTS

Land plants are found only in the upper beds of the Humevale Formation, entering about the horizon of Middendorp's Quarry, Kinglake West. *Hostimella* sp. and abundant fragmentary remains occur in narrow bands in the sandstones of the Flowerdale Member. Many beautifully preserved specimens of *Baragwanathia longifolia* Lang & Cookson are present in fine siltstone (Locality A82, 376,064 Yea Military Map) high in the Humevale Formation, just below the conglomerate of the Flowerdale Member (Pl. XLVIII, fig. 2). Thus, the *Baragwanathia* spp. are considered to occur on a similar horizon to that of Collins's Quarry, Kinglake West (see Table 2). Several spiny plants found at Locality A82 resemble species of *Psilophyton* found in the Lower Devonian of Maine, U.S.A. (Dorf and Rankin 1962).

FAUNAL SUCCESSION AND PALAEO-ECOLOGY

Fossils are generally rare in the Yan Yean Formation, and although sandstones at Localities F31 and X56 have yielded an abundant fauna, these beds are certainly not typical of the formation as a whole. Fossils first become common over a wide area in the Mt Phillipa and Clonbinane Members, and the lower 2,000 ft of the Humevale Formation at Eden Park contain an abundant shelly fauna in siltstones and fine sandstones. The notable feature of the Humevale siltstones is the lateral and vertical variation in abundance of fossils and grain size of the sediments. The strata at Eden Park are slightly coarser gained and much more fossiliferous than the stratigraphically equivalent lower 2,000 ft of siltstones at Humevale. Similarly, the upper beds at Kinglake West are richly fossiliferous while the sediments at Kinglake East are finer grained and contain an impoverished fauna. There is also a slight decrease in grain size and fossil content of the sediments to the N., but the differences are not as marked as those to the E.

TABLE 2
Correlation Chart



A general shallowing of the sea is the most likely explanation for the great increase in shelly fossils from the Yan Yean to the Humevale formation. The lateral variations in abundance of fauna and grain size of the Humevale siltstones indicate deeper water to the E., and to a lesser extent, the N. Thus, with continued shallowing the shelly faunas were able to migrate to the E. The conglomerate of the Flowerdale Member does not indicate shallow water conditions; evidence will be given in a later section that it is a slump conglomerate.

Age of the Sediments

Table 2 shows correlation and probable age of the important sections within the area mapped. An attempt is here made at correlation with other Victorian Siluro-Devonian sequences, and also with the European type section.

Yan Yean Formation

The Yan Yean Formation may be confidently correlated with the Lower Ludlovian, based on the graptolites *Monograptus colonus, M. varians* var. *pumilus*, and *M. bohemicus*, these forms being most common in the *Monograptus nilssoni* Zone of the Ludlow Shales (Elles and Wood 1918). *M. bohemicus* has been found only a few hundred feet below the base of the Humevale Formation, indicating that the Yan Yean Formation probably is not younger than the Middle Lower Ludlovian, although it may extend down into the Wenlockian in the St Andrews-Hurstbridge district. Thus, the Yan Yean Formation may be regarded as Melbournian in age (Jones 1927, Thomas and Keble 1933).

The sequence in the Wandong district—lower mudstones containing graptolites; sandstones and siltstones with starfish, *Dalmanites*, and numerous other shelly fossils; and finally mudstones with *Encrinurus* and *Aegiria*—is similar lithologically and palaeontologically to the Dargile Beds at Heathcote, which Thomas (1937) showed to be also of Lower Ludlovian or Melbournian age. Future mapping may eventually link the Wandong and Dargile beds by means of the Chintin Beds of the Kilmore district.

Humevale Formation

Since the Humevale Formation directly overlies the Yan Yean Formation, its lower beds must represent the Upper Ludlovian. If the graptolite found at Locality X50 just above the Clonbinane Member is *Monograptus dubius* var. *thuringicus*, it would mean that the Clonbinane Member is not younger than the Middle Ludlow. This fits well with the proximity of Lower Ludlow graptolites to the base of the member.

The lower 2,000 ft of siltstones at Eden Park, and the Clonbinane Member contain several species common in the Yeringian sediments at Lilydale, Gill (1942) regarding *Pleurodictyum megastoma* as indicating a Lower Devonian age. However, Hill (1943) does not discount the possibility of the genus *Pleurodictyum* extending down into the Silurian, while Philip (1962, p. 166) notes that *Pleurodictyum* has been found in the Silurian of North America. *Atrypa 'reticularis', Leptaena 'rhomboidalis', Plectodonta bipartita* and *Actinopteria boydi* are also present in the Lower Devonian sediments at Lilydale, and there has been a tendency to regard several of these forms as characteristic Yeringian fossils. Their presence in the lower beds of the Humevale Formation has thus extended their local range down into the Ludlovian. The specimens of *Monograptus* showing *'uncinatus'* type thecae, found low in the Humevale Formation at Break-o'-Day, are probably the proximal portions of biform Upper Ludlow graptolites.

The two upper divisions of the Humevale Formation at Kinglake West have the following species in common with the type Yeringian strata (Gill 1942, 1945b) considered Lower Devonian in age:

Chonetes ruddockensis Gill, *Plectodonta bipartita* (Chapman), *Notanoplia australis* (Gill), *Gravicalymene angustior* (Chapman), *Pleurodictyum megastoma* McCoy, *'Lindstroemia' yeringae* Chapman, and *L. ampla* Chapman.

The following species from Middendorp's and Collins's Quarries, Kinglake West (which both occur within a stratigraphic thickness of 800 ft), are found in the upper portions of the Boola Beds at Tyers, Gippsland, regarded by Philip (1962) as Lower Devonian in age:

Pleurodictyum megastoma McCoy, *Plectodonta bipartita* (Chapman), *Notanoplia australis* (Gill), *Chonetes cresswelli* Chapman, *Lissatrypa lenticulata* Philip, *Gravicalymene angustior* (Chapman), *Crepidosoma kinglakensis* Withers and Keble, and *Notoleptaena* sp.

The Flowerdale Member, considered to be on a similar horizon to that of Collins's Quarry, has the following species in common with the Boola Beds:

Favosites aff. *forbesi* Edwards and Haime, *Pleurodictyum megastoma* McCoy, *Chonetes cresswelli* Chapman, *Eospirifer* aff. *togatus* (Barrande), *Isorthis festiva* Philip, *Lissatrypa lenticulata* Philip, *Notanoplia australis* (Gill), *Plectodonta bipartita* (Chapman), *Gravicalymene angustior* (Chapman), *Tyersella* sp., and *Notoleptaena* sp.

Thus the two upper divisions of the Humevale Formation are probably of Lower Devonian age, with the Silurian-Devonian boundary between 2,000 ft and 4,000 ft above the top of the Yan Yean Formation.

The following corals and brachiopods from the conglomerate of the Flowerdale Member—*Syringaxon, Favosites* cf. *forbesi*, *Eospirifer* aff. *togatus*, *Isorthis festiva*, *Tyersella*, *Delthyris*, and *Rhizophyllum*—have not been found elsewhere in the Humevale Formation. Philip (1962, p. 137) noted that *Tyersella* and *Eospirifer* survived the facies change from mudstone to conglomerate in the Tyers area, and it is probably the distinctive facies which restricts the above forms to the conglomerate of the Flowerdale Member.

The occurrence of *Baragwanathia longifolia* at Locality A82 immediately below the conglomerate of the Flowerdale Member means that this plant, believed to be the world's oldest vascular land plant (Lang and Cookson 1934), ranges up into the Lower Devonian, a conclusion also reached by Philip (1962), who found a solitary specimen of *Baragwanathia* high in the Boola Beds at Tyers. Thus, together with Jaeger's (1959) study, evidence is accumulating that *Baragwanathia* is not solely a Lower Ludlow plant and that the commonly associated *Monograptus 'uncinatus'* of the Yea-Alexandra district has been wrongly identified, being in reality an Upper Ludlow graptolite. Jaeger (in Philip, p. 246) considers that the graptolite associated with *Baragwanathia* is his *Monograptus praehercynicus*, which possibly extends into the Lower Devonian. If this identification is upheld, it will be necessary to postulate a lateral variation in facies during the Upper Ludlow from shelly in the Whittlesea-Kinglake West district to graptolitic in the Yea district. As mentioned above, there is evidence within the Kinglake district that the sea did deepen to the E. and N., and this will be further supported below.

Sediments

PETROGRAPHY

For purposes of description the sediments have been divided into three groups—Lutites, Arenites, and Rudites.

LUTITES

Siltstones and mudstones form over 80% of the total sequence. A detailed petrological and micrometric study was made of the siltstones exposed in Running Ck, Kinglake West, in the hope of finding a gradation in composition, diagenesis or grain size throughout a thickness of over 3,000 ft. Although local variations were present, no systematic change of any sort was detected, and the thin sections were indistinguishable from those of siltstones from elsewhere in the Humevale and Yan Yean formations.

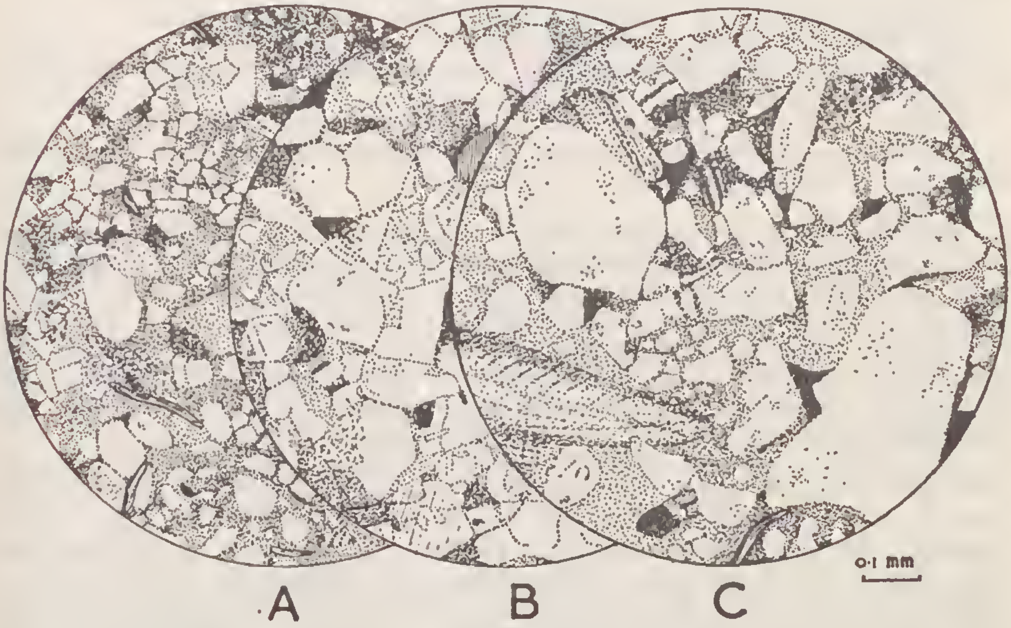


FIG. 4—a. Siltstone from Running Ck, Kinglake West.
b. Sandstone from the Clonbinane Member.
c. Poorly sorted greywacke from the Flowerdale Member.

Sections 8476-8482 from Running Ck, Kinglake West (arranged in stratigraphical order), Section 8483 from Wandong Quarry, and Sections 8484 and 8485 from Pheasant Ck, Kinglake Central, show that the siltstones consist predominantly of angular quartz, with occasional felspar grains and plates of mica, set in a greeny-brown slightly pleochroic groundmass (Fig. 4a). The following minerals have been identified in thin section:

Quartz—by far the most common detrital mineral, in small angular grains, and only rarely water-rounded; often contains small bubbles and needle-like inclusions, probably rutile; rarely shows strain extinction.

Felspar—occasionally as angular grains about the same size as the quartz, and rarely as small, tabular crystals. Varieties include microline, showing cross-hatched twinning; orthoclase, relatively common in some sections, and occasionally exhibiting perthitic intergrowth; plagioclase ranging from albite to andesine, with oligoclase being most common.

Biotite—as fresh or partially bleached plates and laths arranged roughly parallel to the bedding; local alteration to chlorite.

Muscovite—in ragged laths, similar in size and orientation to the biotite.

Sericite—probably partly authigenic, and partly allogenic, as an alteration product of some felspar grains, and an important constituent of the groundmass.

Iron ore—common as small grains, occasionally with euhedral outline. Ilmenite predominates over magnetite, while pyrite is rare.

Leucoxene—scattered grains as an alteration product after ilmenite.

Zircon—in minute prisms, most water-rounded.

Tourmaline—in small, green-brown prisms.

Chlorite—the greeny-brown, slightly pleochroic material of the groundmass is probably a variety of chlorite.

Calcite—in irregular patches in the groundmass of some sections.

? Kaolin—as an alteration product of the felspar grains, and also a probable constituent of the groundmass.

Even though the sections were cut from blue-black, fresh looking rocks, most show some alteration due to diagenesis or surface weathering. Quartz grains have been occasionally embayed and replaced at their borders by the chloritic matrix and calcite, small neighbouring grains with the same optical orientation suggesting replacement by the groundmass along fractures in a larger grain. Some of the felspars have been partially to completely altered to sericite and kaolin, biotite partly bleached or chloritized, and occasional pseudomorphs of chlorite and iron ore have possibly been derived from detrital amphibole or pyroxene.

Some patches or bands within the siltstones contain many quartz grains, while other patches are composed mainly of the chloritic matrix, although generally the rocks are of a remarkably even texture. A micrometric analysis was carried out to determine the ratio of clastic grains to matrix in the siltstone, the method used being that employed by Crook (1956). This involved measuring linearly the ratio of clastic grains to matrix along random traverses of sections seen under high power. The average results were 50·9% clastic grains, 49·1% matrix. Sections cut parallel to the bedding gave a slightly higher percentage clastic grains than did sections cut at right angles from the same hand specimen, probably due to the settling of tabular grains along the bedding.

The average diameter of several hundred clastic grains in Sections 8478 and 8479 was measured with a micrometer slide. Krumbein and Pettijohn (1938, p. 130) found that the apparent mean diameter of grains measured in thin section is approximately 24% smaller than the actual mean diameter. The measurements were corrected by this amount and plotted against their relative frequencies. The curves were closely symmetrical about the mode, in both cases 57 microns, which falls within the range of 'coarse silt' in the modified Wentworth Scale, given in Dunbar and Rodgers (1957, p. 161). Thus, the field classification of these rocks as siltstones is confirmed, as Dunbar and Rodgers, p. 163, state that a sediment as a whole is 'ordinarily assigned to that class containing either the mode, the median, or the geometric mean of the size distribution'.

Two fresh samples from the 'limestone' at Eden Park yielded 22·9% and 26·0% carbonate, and as the size of the detrital quartz grains is similar to that of the surrounding sediments, these beds are best described as calcareous siltstones.

ARENITES

Fine-grained sandstones are common in the Yan Yean Formation and form the bulk of the Clonbinane Member, while coarse-grained, poorly sorted sandstones and grits occur in the Flowerdale Member high in the sequence.

Section 8488 is typical of the sandstones of the Clonbinane Member (Fig. 4b), the rock coming from a quarry at Reedy Ck. Angular quartz grains predominate, with occasional grains of orthoclase and twinned oligoclase. Muscovite and biotite are common as laths and plates which lie along the bedding and give the rock its characteristic flaggy split. The matrix of chlorite and sericite is not as common as in the siltstones; small zircon prisms and grains of secondary limonite are also present. Using the method described above, the average diameter of the quartz and felspar grains was calculated to be 132 microns, i.e. within the 'fine sand' range of the modified Wentworth Scale. Thus, although the sediments of this average grain size have some chloritic matrix, they contain no rock fragments and are best described as argillaceous sandstones.

Section 8490 (Fig. 4c) is typical of the grits at Kangaroo Ck, about 3 miles N. of Flowerdale. The rock is poorly sorted, some rounded quartz grains being over 1mm in diameter, although most of the quartz is angular and of sand particle size. Felspar grains are also present, together with rock fragments, often water worn, of quartzite and slate. Fossil remains are preserved as crystalline calcite surrounded by a border of limonite; interstitial calcite is also common in the groundmass and appears to have locally replaced quartz and felspar in embayments and fractures. Laths of muscovite and biotite are often ragged and distorted, indicating that the rock has undergone shearing. The groundmass is composed of a very fine mosaic of quartz grains, with some sericite and calcite. The poor sorting of the detrital grains, the included rock fragments and fine groundmass are consistent with the definition of a greywacke given by Pettijohn (1957); thus most of the arenites of the Flowerdale Member may be classed as gritty greywackes.

RUDITES

The single conglomerate horizon at the base of the Flowerdale Member has been described above in reasonable detail. All the pebbles are of extremely stable rock types, reef quartz and quartzite being the most common. Section 8491 of a quartzite pebble is composed mainly of a mosaic of quartz grains, with a few grains of acid plagioclase, flakes of biotite, and a small amount of chloritic matrix. The absence of any siliceous cement and the interlocking nature of many of the quartz grains suggest that the rock has undergone a certain amount of thermal metamorphism.

HEAVY MINERAL ANALYSIS

Samples from a wide variety of rock types were anlysed for their heavy minerals, in the hope of throwing some light on the origin of the sediments. Samples were taken from: siltstones of the Humevale Formation at Kinglake West and Upper Plenty; sandstone at Collins's Quarry, Kinglake West; and the conglomerate and gritty phases of the Flowerdale Member.

Zircon, rutile and tourmaline were present in all the sediments analysed, being of similar dimensions and relative proportions, although owing to their very small size they were more common in the siltstones than the sandstones and grits. The heavy minerals shown in Slides 8492 to 8498 are described below.

Zircon—typically prismatic, mainly short and stumpy, and terminated by pyramids; colourless to pale blue or pale green, often slightly pleochroic, containing fine needle-like inclusions, iron ore grains and occasional small bubbles; most water-worn to some degree, some being elliptical to almost circular in outline.

Rutile—present in two varieties, although never as abundant as zircon. Most commonly as slender, honey-brown, pleochroic prisms, showing pinacoidal terminations; all slightly water-worn, containing few inclusions. The other variety is smaller, yellow-brown in colour, and more water-worn, being in some cases subspherical in outline.

Tourmaline—commonly as green-brown, strongly pleochroic, stumpy and occasionally slender prisms, terminated with pinacoids; most contain bubbles, with the more slender prisms enclosing dust-like particles of iron ore drawn out in line; generally rounded slightly, occasional grains being elliptical in outline. Krynine (1946) considers this green-brown variety of tourmaline, containing many bubbles and cavities, to be derived from granitic rocks.

Several of the tourmalines show light coloured outgrowths in optical continuity with the main crystal at one end only of the c-axis. Krynine (1946) regards such outgrowths to be of authigenic tourmaline. The small outgrowths on a nearly spherical grain have a somewhat rounded outline and may be water-worn. If this is so it means that the grain is second cycle, which seems likely from its greatly water-worn appearance.

Iron ore—grains of magnetite and ilmenite are common, many having octagonal or prismatic outline. Irregular grains of limonite are abundant in the sandstones from Collins's Quarry.

Micas—Plate of muscovite and biotite are found occasionally in all rock types, being particularly common in the sandstones from Collins's Quarry and the Clonbinane Member.

NATURE OF THE SOURCE ROCKS

The uniformity of the constituent minerals of the sediments suggests similar source rocks were being eroded during the whole time of deposition. Several writers have previously given their opinions as to the nature of the source rocks for the Silurian sediments of the Melbourne district. Jutson (1911) suggested a source composed both of igneous and sedimentary rocks, as did Langford (1916), while Junner (1913) believed that the predominant source rock was igneous, probably granitic.

The following reasons suggest that the sediments were derived in part from granitic igneous rocks:

1. The abundance of muscovite in the sandstones, and fresh biotite in the siltstones.
2. The presence of fresh acid plagioclase, orthoclase and perthite grains in all the sediments.
3. The occurrence of the heavy minerals zircon, rutile and especially tourmaline indicates an ultimate, but does not necessarily prove an immediate, granitic source. However, the heavy minerals showing little or no rounding are likely to be first cycle.
4. The abundance of reef quartz pebbles in the conglomerate of the Flowerdale Member indicates that the source rocks had been subjected to some igneous activity, with the injection of many quartz veins, commonly associated with granitic intrusions.

The absence of metamorphic minerals and the lack of strain extinction in the quartz grains suggest that metamorphic rocks were not an important source for the sediments.

The following points indicate that sedimentary rocks were present in the source terrain:

1. The great rounding of some of the heavy minerals, and the possible water-worn authigenic tourmaline outgrowth suggest second cycle deposition.
2. The great number of quartzite pebbles in the conglomerate is positive proof of the sedimentary nature of at least some of the source rocks.

Thus, a terrain of sedimentary rocks, intruded by granites and associated quartz veins, seems the likely source for the sediments of the Kinglake district, rapid erosion having allowed deposition of fresh felspar and micas in the neighbouring Siluro-Devonian sea.

Sedimentary Structures

Bedding Features

Structures within this division include graded bedding, cross-bedding, ripple-drift bedding, sole markings and scour-and-fill.

Graded Bedding

In the Yan Yean Formation, occasional sandstone beds from 6 to 18 in. thick have sharp junctions with the overlying and underlying siltstones, but show slight vertical grading, as do some of the thin sandy laminae in the siltstones and mudstones. The sandstones of the Clonbinane Member are also occasionally graded, gradually passing from fine sand up into thin shale beds, the grading often being increased by the presence of flat mud pellets lying along the base of the sandstones. The greywackes and grits of the Flowerdale Member afford the best examples of graded bedding, with beds about one foot thick being gritty at the base and grading up into medium to fine sandstone.

However, the many thousands of feet of mudstones and siltstones, about 80% of the total sequence, are not graded at all. Thus, graded bedding must be regarded as the exception rather than the rule.

Laminated Bedding

Many of the sandstones of the Yan Yean Formation and Clonbinane Member are well laminated (Pl. XLVIII, fig. 3), due either to slight changes in grain size, or layers of organic fragments. However, laminated bedding is not common in the greywackes and grits of the Flowerdale Member.

Cross-bedding and Ripple Bedding

Cross-bedding is common in the sandstones of the Yan Yean Formation (Pl. XLVIII, fig. 3), the tops of the cross-laminae generally being truncated by the overlying bed, while the lower portions show a sigmoidal curvature. The cross-bedding at any one exposure has similar directions of dip, and this was recorded at many localities. The sandstones of the Clonbinane Member also show cross-bedding, although it is not as common as in the Yan Yean Formation. Few good examples of cross-bedding were observed in the gritty beds of the Flowerdale Member. In general, cross-stratified beds are seldom more than 2 in. thick. The average of 76 foreset inclinations was 25°.

Current ripple bedding is often associated with cross-bedding, although ripple-mark is not common, due in part to limited suitable exposure, and also probably to the erosion of the crests prior to the deposition of the following bed.

SOLE MARKINGS

Sole markings, consisting mainly of flute casts and occasionally worm tracks, are restricted to the sandstones and grits, although seldom observed in situ. The base of a sandstone block from the Yan Yean Formation, Whittlesea, contains many small flute casts and grooves showing a definite direction of elongation (indicated by the pen in Pl. XLIX, fig. 1), there also being a tendency for the flute casts to be arranged in diagonal rows, making an angle of approximately 50° with the direction of elongation. This pattern is similar to that illustrated by Kuenen (1957, p. 237). Larger and smoother flute casts occur in the sandstones of the Clonbinane Member, as shown in Pl. XLIX, fig. 2. Cross-bedding in this block indicates a current direction parallel to the long axis of the grooves (arrow), confirming that such sole markings are due to scouring of the sea floor by current action prior to the deposition of the sandstone beds. Flute casts and grooves were also observed in the greywackes of the Flowerdale Member.

SCOURS

The smallest scours are associated with current ripple bedding, being common in the sandstones of the Yan Yean Formation. However, only one large scour involving several beds was observed in sandstones of the Clonbinane Member.

SOFT SEDIMENT DEFORMATION

A wide variety of structures due to soft sediment deformation in sandstones and mudstones of the Yan Yean Formation are exposed in a road cutting at Doreen, S. of Whittlesea. Large diapyric injections of mudstone have entirely broken through the overlying sandstones and appear to have a faulted contact with neighbouring beds. Smaller mudstone injections which have not completely pierced the sandstone above are associated with downward projecting sandstone lobes, commonly referred to as load casts. Small folds at right angles to the tectonic strike of the district indicate that some lateral movement or sliding of the sediments has taken place, while greatly contorted bedding (Pl. XLIX, fig. 3) is proof of the highly mobile nature of the mudstones during deformation.

The best explanation for the development of load casts (Hills 1940, Kuenen 1953, Kelling and Walton 1957) is the settling of pockets of sandstone under gravity into the fine, unconsolidated sediments below, tongues of mudstone being simultaneously injected up into the sandstone. The asymmetry of several of these mudstone injections suggests differential horizontal movement of the sediments while still unconsolidated (Hills 1940).

Several laminated sandstone beds of the Yan Yean Formation show a series of cuspate anticlines in the upper laminae which gradually diminish in size towards the base of the bed. These distortions are similar to the 'convolute bedding' of Kuenen (1953, p. 1057-58), who considered they were due to gradual deformation of a bed in a quicksand condition but which had not undergone horizontal movement. This convolute bedding contrasts sharply with the chaotic disturbances in some of the mudstones at Doreen.

MECHANISM OF DEPOSITION OF ARENITES AND RUDITES

Kuenen and Migliorini (1950) postulated turbidity currents as a mechanism by which graded arenaceous beds could be deposited amid pelagic clay in the deeper

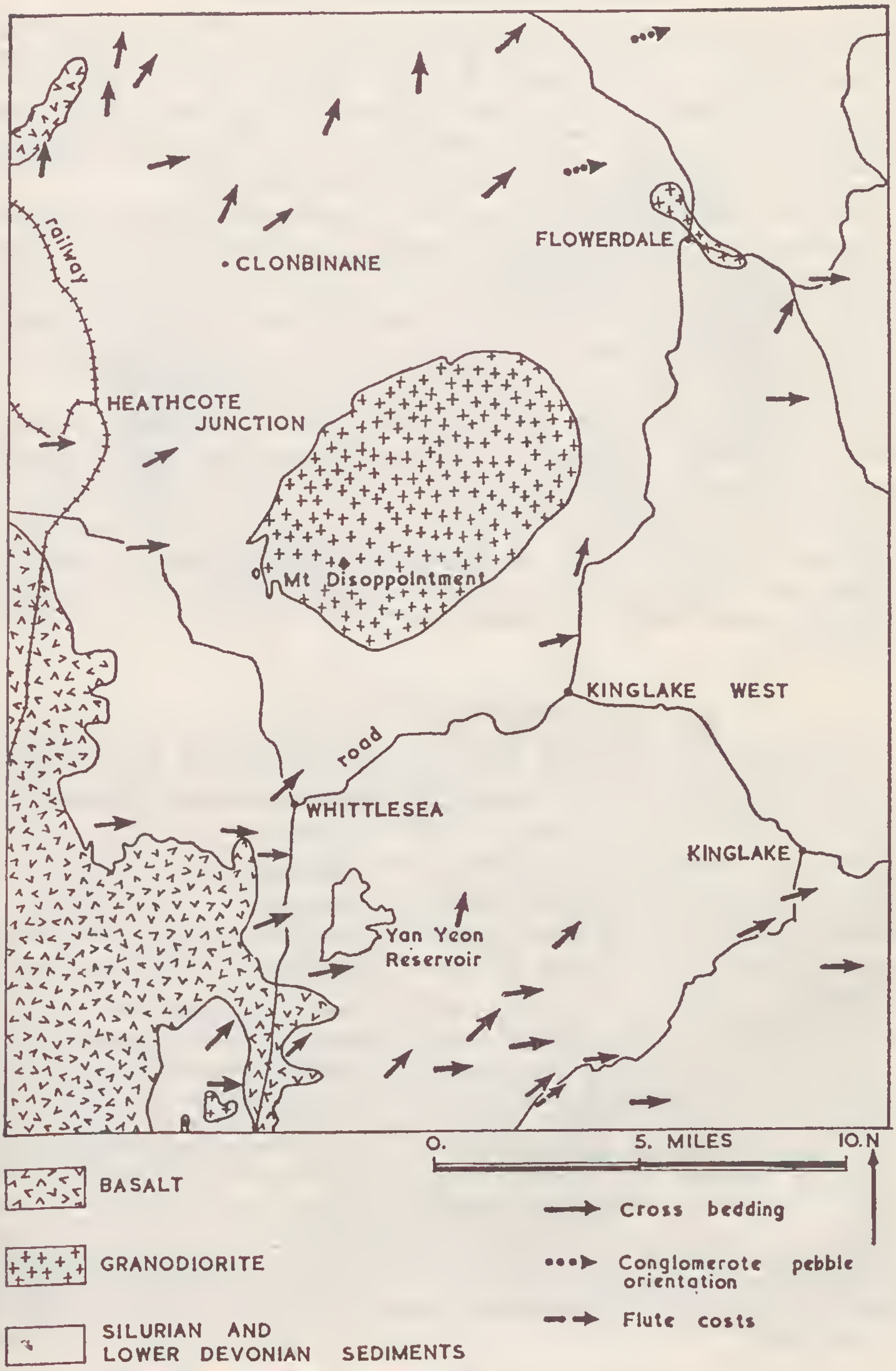


FIG. 5—Palaeocurrent directions within the area investigated. Vector mean of 77 cross-bedding measurements strikes 50°; vector magnitude 70%.

portions of ocean basins. Further work by Kuenen (1953, 1957, etc.) revealed that many sedimentary structures, such as cross-bedding, flute casts, load casts, convolute bedding, etc., were common in graded sequences, and he attributed them to the action of turbidity currents. However, Murphy and Schlanger (1962) showed that a number of the above structures, especially cross-bedding, convolute bedding, and load casts may occur in a non-turbidite sequence. Hence, regular graded bedding appears to be the only criterion for turbidity current deposition.

Thus, the graded arenites of the Yan Yean Formation and Clonbinane Member are tentatively regarded as having been deposited by strong sediment-laden bottom currents, and the interbedded mudstones and shales in still waters between periods of current action. However, the excellent preservation of delicate crinoids and brittlestars in the sandstones of the Clonbinane Member and also at Collins's Quarry, Kinglake West, does not appear to support the theory of deposition by turbulent bottom currents. It is possible that some of these finer sandstone beds were deposited by currents that flowed over a long period of time.

The beds of the Flowerdale Member appear to be the only sediments studied to have been deposited by large-scale slumping and turbidity currents. The conglomerate, which generally overlies fine siltstones presumably of fairly deep water origin and often contains a muddy matrix, may be best explained by slumping and redeposition in a deeper part of the basin, as suggested for the Lower Silurian conglomerate at Keilor by Hills and Thomas (1954). Incorporated mud fragments indicate erosion of consolidated sediments during the slumping. A turbidity current origin also seems likely for the strongly graded grits and greywackes overlying the conglomerate.

PALAEOCURRENT DIRECTIONS

Cross-bedding was the most useful palaeocurrent indicator. The attitudes of the cross-laminae were measured, and their original directions of dip calculated by means of a stereogram. Fig. 5 shows that the overall movement of currents was to the E. or NE., with the southerly component becoming more evident to the N. In returning the beds to the horizontal, corrections were made for plunge of the folds, although none for possible rotation of the beds around a vertical axis, which may have occurred in the N. portion of the area mapped.

Flute casts and grooves where observed in situ indicated a current direction consistent with the cross-bedding, the apices of the flute casts being taken to point up current.

Kopstein (1954) found that in the Harlech Dome conglomerates of slump or turbidity current origin, the longest axes of elongated pebbles lay parallel to the current direction indicated by cross-bedding and sole markings of associated beds. There was also a tendency for the coarsest fraction of elongated pebbles to slant downcurrent at angles up to 45°, with plunges of 25° or less being most frequent. This method of current measurement was applied to the conglomerate of the Flowerdale Member. The orientations of the long axes of 57 elongated pebbles from ½ in. to 3 in. in length were recorded from four widely separated localities, plotted on an equal area projection, and restored to their attitudes at the time of deposition. The final contoured diagram (Fig. 6) shows a strong E.-W. lineation of the pebbles, with the maximum striking 82° and plunging 3° E. This is consistent with the other palaeocurrent directions and the occurrence of the largest pebbles at Locality Y97.

FIG. 6—Orientation of the long axes of 57 elongated pebbles from the Flowerdale Member.

PALAEOSLOPE AND SOURCE OF SEDIMENTS

Since sediment-laden currents or slumps act under gravity, it is reasonable to assume that they would flow down the steepest slope of the sea floor. If momentum were great enough a current might possibly flow obliquely across the sloping sea floor where uneven topography existed, but it is hard to envisage this happening over great distances. Hence it seems likely that the sea floor sloped to the NE. within the area investigated. This is supported by the lateral variation in facies of the Humevale Formation, as noted above.

As stated previously, the terrain which supplied the sediments of the Kinglake district probably consisted both of granitic and sedimentary rocks. The easterly slope of the Siluro-Devonian sea floor suggests that this ancient terrain lay to the W. of the area investigated.

SEDIMENTARY HISTORY

The great thickness of sediments (approximately 14,000 ft) deposited within the Kinglake district in the relatively short time range from the Lower Ludlovian to the Lower Devonian indicates both rapid erosion and deposition in a subsiding geosyncline.

Fairly deep water conditions appear to have prevailed in the Lower Ludlovian, with the deposition, possibly from turbidity currents, of cross-bedded and occasionally graded arenites in the Yan Yean district. However, at Wandong the absence of thick arenites and the presence of numerous mud-burrowing trilobites suggest that shallower conditions prevailed.

During the Upper Ludlovian, shallowing of the sea is indicated by the more numerous fossils and change in lithology. The beds at Eden Park were probably deposited in shallow water, shelly fossils being abundant enough to form a 'limestone' band, while to the N. the sandstones of the Clonbinane Member were deposited with the aid of currents from the SW.

The thick, monotonous siltstones of the Humevale Formation suggest rapid deposition in a shelf environment during the Lower Devonian, with shallow water in the SW. indicated by the abundant fauna of the Kinglake West district. These sediments are similar to the massive siltstones of the Mesozoic and Tertiary of New Zealand, considered by Kingma (1960) to be marine shelf deposits. The finer siltstones and mudstones of the Flowerdale-Yea district containing excellently preserved land plants, and the presence of the slump conglomerate suggest deeper water conditions to the NE. during the Lower Devonian.

These shallowing movements were possibly associated with the Bowning Orogeny, although the uniformity of the current directions indicates that the major folding of the Tabberabberan Orogeny had not yet commenced.

PALAEOGEOGRAPHY OF CENTRAL VICTORIA IN SILURO-DEVONIAN TIME

As the tectonic strike of the sediments of Central Victoria is roughly N.-S., it is likely that the trough was elongated meridionally. No Silurian or Lower Devonian sediments have been recognized W. of the Cambrian Heathcote Axis, and it is interesting to speculate on the position of the W. shore-line in Lower Devonian time. Packham (1960) considered that the 'western margin of sedimentation must have been some distance to the west of Heathcote, since the Silurian and Devonian sediments there are over 24,000 ft thick'. However, the upper 10,000 ft of sediments at Heathcote, represented by the McIvor and Mt Ida Formations (Thomas 1937), consist predominantly of abundantly fossiliferous sandstones, suggesting near-shore conditions.

Although Kuenen has stressed the importance of longitudinal filling of oblong sedimentary basins, the W. portion of the Victorian Siluro-Devonian trough appears to have been filled transversely from the W.

The terrain from which the sediments of the Kinglake district were derived is not evident, although the deformed Proterozoic and Cambrian deposits of the Adelaide Geosyncline probably contributed much detritus to the Victorian trough from the Ordovician to the Devonian. Hills and Thomas (1954, p. 131) stated that 'the considerable lithological change from the top of the Silurian to the Lower Devonian, with the incoming of conglomerates, is perhaps to be correlated with the Bowning Orogeny. . .'. The source of the conglomerates, at least within the area investigated, being from the W., suggests that the Bowning Orogeny extended its influence to W. Victoria, with the possible uplift of further potential source rocks.

The restriction of *Baragwanathia* to the central portions of the trough is probably due to the facies there having been favourable for its preservation. This is consistent with the findings of Kingma (1960), who showed that the sediments of the New Zealand geosynclinal basins are most coarse grained and strongly

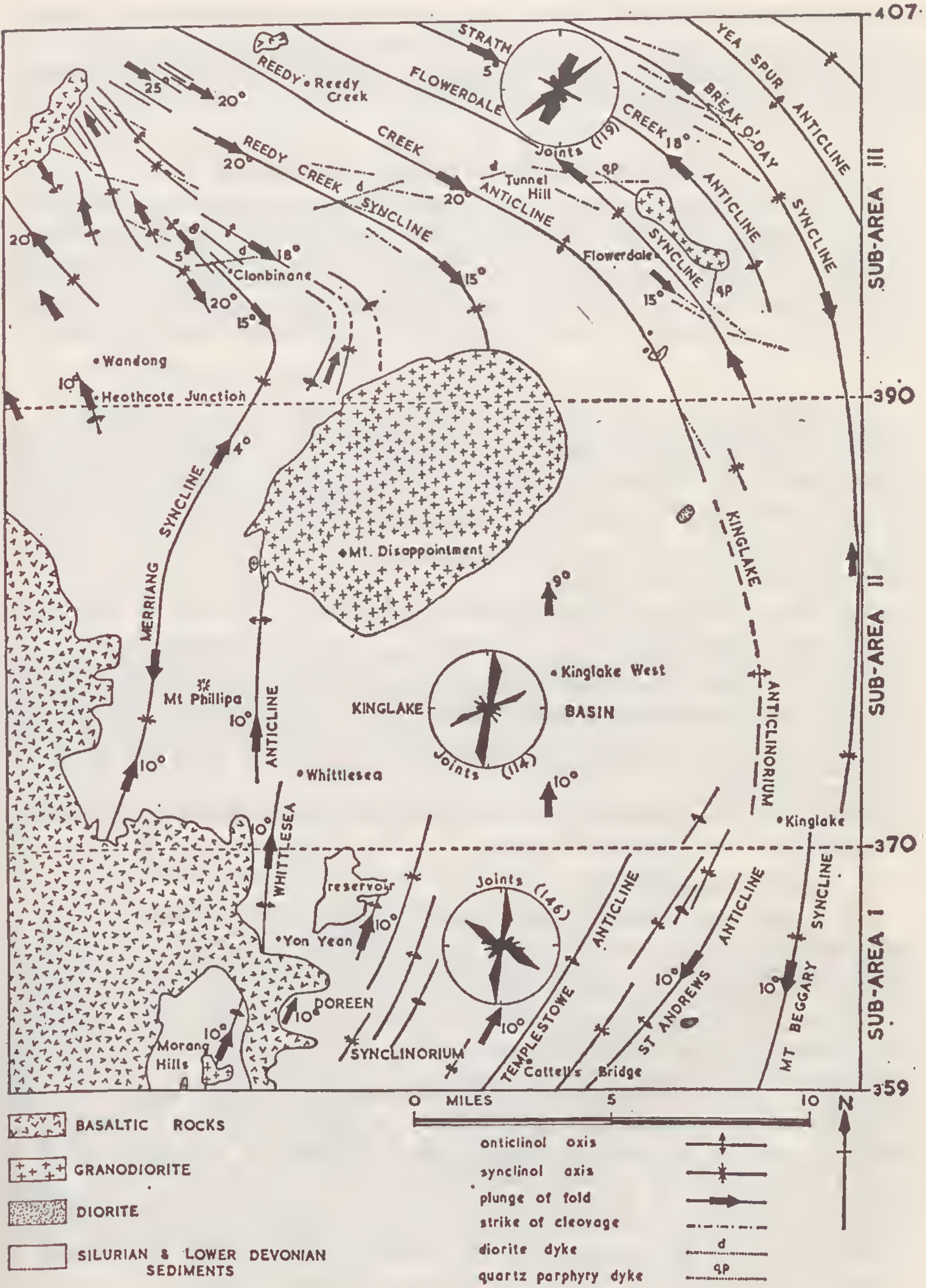


FIG. 7—Synoptic Structure Plan of the Kinglake and surrounding Districts.

scoured nearest the probable source, while plant material is most abundant in those areas farthest from the probable source. Similarly, Banks (1962) considered that the deep-water Mathinna Beds of NE. Tasmania, containing abundant plant remains including *Hostimella*, are probably equivalent to the Siluro-Devonian shelf deposits of the Eldon Group to the W.

Structural Geology of the Kinglake District

The Silurian and Lower Devonian sediments of Central Victoria were moderately to strongly folded in Middle Devonian times during the Tabberabberan Orogeny. The folds are mainly sub-meridional in trend, although locally strongly arcuate, as noted by Thomas (1939). The structure of the area investigated is summarized in Fig. 7, the notable feature being the 90° change in trend of the folds from approximately N. 25°E. at Yan Yean to E. 25°S. at Reedy Ck.

FOLDING

The general lack of cleavage in the sediments, the uniform thickness of individual beds across small folds and crush-zones, and occasional slickensided bedding planes indicate that the strata have been bent into concentric or parallel folds. This appears to be the dominant type of folding developed in the Silurian and Lower Devonian sediments of West-Central Victoria (Jutson 1911, Junner 1913, Hills 1941), contrasting sharply with the shear folding in the Ordovician rocks W. of the Heathcote Axis.

The major structural features are described below, starting in the W. of the area and working from S. to N.

W. and N. of Heathcote Junction, the mudstones and sandstones of the Yan Yean Formation have been thrown into a series of tight, asymmetric folds, striking N. 30°W. and plunging approximately 10°NW. The W. limbs of the anticlines are generally the steeper, while locally there is evidence of overfolding to the W. However, E. of Heathcote Junction the strata dip constantly to the E. as far as the Clonbinane district.

Most of the area remaining may be divided into four persistent major folds or 'fold-zones':

1. The Merriang Syncline:

The S. portion of this fold was first mapped and named by Jutson (1908) in the Eden Park district. Here it is broad and asymmetrical, the steeper dips being on the E. limb, while gently dipping beds in the centre of the fold indicate a northerly plunge of about 10°. N. of Mt Phillipa the syncline narrows and plunges to the S., thus forming an elongated basin structure with the beds at Eden Park. At Upper Plenty the trend changes from N.-S. to N. 30°E., the fold running for about 6 miles roughly parallel to the NW. boundary of the Mt Disappointment Granodiorite and plunging about 5°NE. Two miles S. of Clonbinane the Merriang Syncline suddenly swings to the W. through 70° to a trend of N. 40°W., while the plunge again reverses to 10°SE. The syncline at this bend is asymmetric, having dips of up to 45° on the E. limb; few greater than 20° occur for over 2 miles to the W. of the axis. At Clonbinane, the syncline breaks down into numerous tight folds trending NW. and plunging either NW. or SE. This type of close folding is typical of the NW. corner of the area mapped, the anticlines often having near-vertical E. limbs, so exposing with each fold progressively older beds to the W.

2. The Whittlesea Anticline:

The anticline passing through the Morang inlier is probably a southerly extension of this fold. N. of the Morang basalt, the Whittlesea Anticline runs almost due N. for about 4 miles with dips seldom exceeding 60° on either limb, the crest indicating a plunge of 10°N. At Whittlesea, the apparent displacement of the fold over ½ mile to the W. suggests faulting, although scarcity of exposure makes interpretation difficult. To the W., a number of minor S.-plunging folds indicate some complexity to structure, but they do not persist far to the N. After displacement the Whittlesea Anticline continues due N., still with a plunge of 10°N., until truncated by the Mt Disappointment Granodiorite, a small apophysis intruding S. along the fold axis for about ½ mile. N. of the granodiorite the fold emerges as an anticlinorium, which follows the Merriang Syncline around the sharp bend to the W. and merges with the tight folding N. of Clonbinane.

3. The Doreen-Kinglake West-Reedy Ck 'Synclinal':

E. of the Whittlesea Anticline in the Yan Yean district is a large synclinorium about 5 miles wide and trending approximately N. 28°E., composed of at least 6 small folds each less than a mile apart. This structure has been named the Doreen Synclinorium after the nearby township of Doreen. Dips of 65° are common, numerous small drag folds and crush-zones indicating a northerly plunge of 10° or more.

The synclinorium continues NE. for about 5 miles, the folds gradually dying out, until E. of the Yan Yean Reservoir it is represented by a single broad syncline. This synclinal structure, over 12 miles wide and continuing N. for more than 15 miles, has been named the Kinglake Basin. Within the greater part of this structural basin the thick siltstones of the Humevale Formation are low-dipping, generally preserving only the northerly plunge of about 10°. A notable feature is that the Mt Disappointment Granodiorite lies almost entirely within the Kinglake Basin, just cutting across the Whittlesea Anticline on the W.

N. of Kinglake West the strike swings gradually to the W. and the basin narrows until it merges into the NW.-trending Reedy Ck Syncline, named after the creek which flows for several miles within this fold. The syncline plunges from 15° to 20° SE., narrowing to the NW. where it breaks down into several smaller SE.-plunging folds, similar to those of the Clonbinane district.

4. The Cottell's Bridge-Kinglake-Flowerdale 'Anticlinal':

E. of the Doreen Synclinorium there is much close folding and puckering, indicating a northerly plunge, but the predominant dip is to the W. until at Cottell's Bridge the northerly extension of the Templestowe Anticline (Jutson 1911) is reached. Further minor folds occur between the Templestowe Anticline and another major fold to the E., here named the St Andrews Anticline, which plunges from 10° to 15°S., the synclinal area between the anticlines possibly representing the northerly continuation of Jutson's Bulleen Syncline. E. of the St Andrews Anticline is the broad, asymmetric Mt Beggary Syncline plunging at 10°-15° to the S.

Proceeding N. towards Kinglake, the Templestowe and St Andrews Anticlines merge into an anticlinorium, containing many smaller folds showing a great variation in strike and plunge. Areas of puckering, curvature of strike, reverse faults, slaty cleavage, strong jointing, and numerous small quartz reefs are all characteristic of the structure, named the Kinglake Anticlinorium. This structure continues in a northerly direction for about 6 miles, with strikes gradually swinging to the W., until it merges into the NW.-trending folds of the Flowerdale district. A large syncline containing the fossiliferous beds at Kinglake East has been traced to the N. just inside the E. boundary of the area mapped, and appears to be a continuation of the Break-o'-Day Syncline.

NE. from the Reedy Ck Syncline a remarkably simple type of folding extends well beyond the area investigated. These folds trend in a north-westerly direction, varying from E. 30°S. at the Reedy Ck Anticline to E. 45°S. at the Yea Spur Anticline, and are evenly spaced about 2 miles apart. With the exception of the Reedy Ck Anticline at Tunnel Hill, these folds have simple, relatively sharp turnovers, with about 6,000 ft of sediment, dipping between 60° and 70°, on each limb. The anticlines of this series often show signs of tension, while slates are present in the cores of the synclines. Plunges are shown in Fig. 7.

Fold Analysis

The area investigated may be divided into three sub-areas, each with its own characteristic fold pattern. The boundary lines of these sub-areas, shown in Fig. 7, are the E.-W. grids 359, 370, 390 and 407.

FIG. 8—ΠS diagram for the Yan Yean district (Sub-area i).

Sub-area (i):

The Yan Yean-St Andrews district, between E.-W. grids 359 and 370. Here the general trend is NNE., the folds being close together with moderately to steeply dipping limbs. Many of the folds are not persistent, dying out, to be replaced *en echelon,* with displacements of up to one mile.

Fig. 8 is the ΠS diagram for the folds between the Whittlesea and St Andrews Anticline, β plunging 16° on a bearing of 26°. This is consistent with the regional fold trend and the few observed values of B. The maximum on the R.H.S. of the diagram indicates the predominance of westerly dipping beds, due to most of the measurements being taken on the E. limb of the Doreen Synclinorium. Local deviations in fold trend probably account for the S girdle not intersecting the maxima at both ends of the diagram.

Sub-area (ii):

The Whittlesea-Kinglake district, between E.-W. grids 370 and 390. The folding here is characterized by N.-S. trending anticlines and broad synclines, section BB′ (Fig. 2) from the Merriang Syncline to the Kinglake Anticlinorium illustrating the magnitude of the Kinglake Basin.

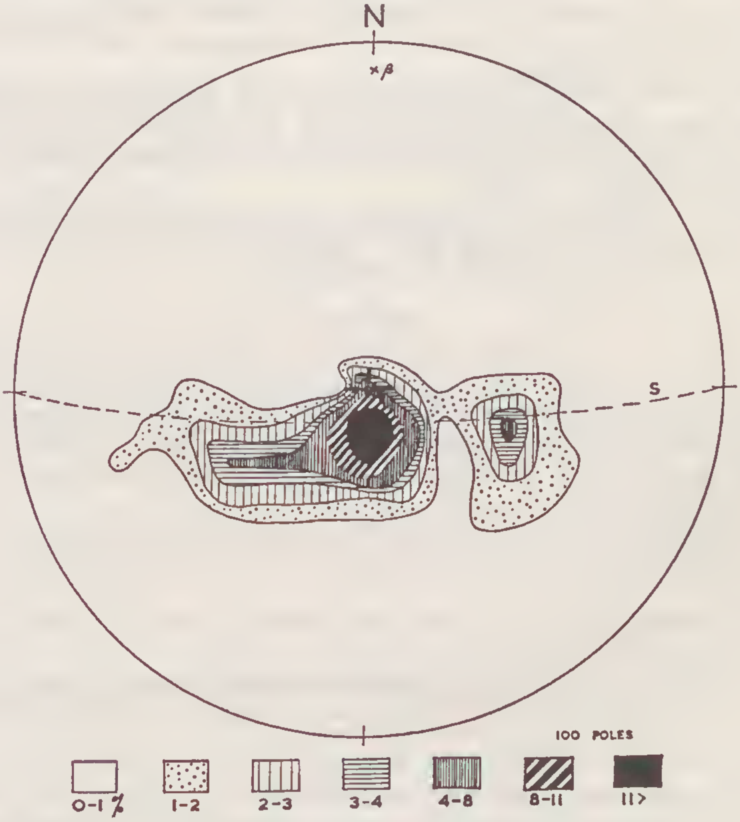


Fig. 9—ΠS diagram for the Kinglake district (Sub-area ii).

The ΠS diagram for the Kinglake Basin (Fig. 9) shows β plunging 9° due N., the maximum in the centre of the diagram being due to the great expanse of unfolded beds present. Here the regional northerly plunge is half that in the Yan Yean district, and continues to decrease until N. of the Mt Disappointment Granodiorite the Kinglake Basin plunges to the S.

Sub-area (iii):

The Clonbinane-Reedy Ck-Flowerdale district, between E.-W. grids 390 and 407. Here the folds trend NW., are equally spaced and of simple structure as described above, section AA′ in Fig. 2 illustrating their uniformity.

No ΠS diagram was drawn for this sub-area, because of the general sharpness and change of plunge of the folds.

FAULTING

Although occasional brecciation and drag of beds were observed, there was no evidence of any large-scale faulting within the area investigated.

Jutson (1908) postulated a N.-trending normal fault along the small anticline E. of the Merriang Syncline at Eden Park. A great complication of dips and strikes occurs in gullies N. of Cemetery Lane, but as the Mt Phillipa Member of the Yan Yean Formation is symmetrically disposed on each side of the Whittlesea Anticline, strike faulting in this district on a large scale is unlikely. However, it is possible that a cross-fault with some sinistral movement displaces the axis of the Whittlesea Anticline just W. of Whittlesea.

Numerous minor faults, both normal and reverse, are exposed in cuttings, but displacements are seldom more than a few feet. Two excellent examples of small reverse faults may be seen in an old cutting near the Whittlesea Cemetery, close to the axis of the Whittlesea Anticline.

Faulting or fracturing on a fairly large scale is indicated by the presence of quartz diorite and quartz porphyry dykes in the N. half of the area, and the linear boundaries of the Mt Disappointment Granodiorite.

JOINTING

Joints occur in all the sediments, but are best developed in the thick, low dipping siltstones as at Humevale and Wandong. Owing to the generally thick soil cover it was not possible to trace individual joint planes beyond a single exposure; however, that major joint sets do persist for miles is indicated by the local control of drainage by joints, e.g. Running Ck, Kinglake West. Most joints are steeply dipping, many being vertical.

To see if there is any relationship between folding and jointing, the same sub-areas used in the fold analysis are adopted. The joint rosettes are shown in Fig. 7.

Sub-area (i):

Most of the joints fall into two sets, one striking between 5° and 15°, the other between 120° and 125°.

The set striking 120°-125° is almost perpendicular to the average fold axis for the sub-area as indicated by the ΠS diagram, and may be classified as 'ac' or cross joints.

The set striking 5°-15°, although deviating by about 10° from the average fold axis, probably represents longitudinal or 'bc' joints.

A third, minor set of joints, striking approximately 85° and making an angle of 59° with the average fold axis, may be regarded as diagonal joints.

Sub-area (ii):

The predominant set of joints strikes between 5° and 15°, deviating by about 10° from the mean fold axis, which strikes N.-S. These are referable to 'bc' or longitudinal joints. The second well-defined set strikes 65°, and are best considered diagonal joints.

No other prominent joint sets are present, although the three remaining maxima may represent poorly developed cross joints and the other set of diagonal joints.

Sub-area (iii):

The joint pattern differs from those of the previous two sub-areas in that there appears to be only a minor development of 'bc' or longitudinal joints, although the deviation from the average fold trend is very slight. However, the close parallelism between auriferous quartz reefs and the trend of the Reedy Ck Anticline, and the fact that the reefs wedge out suddenly with depth (Murray 1884), suggest that the quartz fills longitudinal tension fractures caused by bending of the strata at the anticline.

A major set of 'ac' or cross-joints strikes between 25° and 35° at right angles to the average fold trend. The set striking 55° and making an angle of 63° with the average fold trend may be regarded as diagonal joints.

ORIGIN OF JOINTS

All major sets of joints closely fit the folding within the respective sub-areas and may be classified as either 'bc', 'ac', or diagonal joints.

The cross or 'ac' joints are probably due to tension resulting from slight elongation parallel to the axes of the folds. These have been termed 'extension joints' by Billings (1954).

The longitudinal or 'bc' joints have been described by Billings as 'release joints, similar to those that form at right angles to the axis of compression when the load is released. Other joints with this attitude may be due to tension on the convex side of a bent stratum.' The longitudinal joints of the Kinglake Basin are probably release joints, while those in tightly folded areas are most likely due to direct tension, as at Reedy Ck.

The diagonal joints are probably due to shearing. Ideally, shear joints should occur in two vertical, perpendicular sets lying at 45° to the axis of compression 'a'. This angle, known as β (not to be confused with the pole β of ΠS diagrams) is usually less than 45°, many geologists preferring 30°-35° based on the work of Hubbert (1951), while Moody and Hill (1956) assumed a value of 30°. In sub-areas (i), (ii), and (iii), the values for β (i.e. angle between diagonal or shear joints and the a-axis of the folds) are respectively 31°, 25° and 27°, the average of 28° being comparable with many world-wide field observations. Williams (1959) showed that, at Girvan, β ranges from 10° to 53°, his average of 29° being consistent with results here. Only one of the two possible sets of shear joints is developed in each sub-area, and is probably due to the set which formed first hindering the development of the other by relieving the stresses responsible. No consistent differences were observed between the surfaces of joints due to shear and tension.

Thus the joints within the area investigated were probably formed at the same time as the folding, and indicate that the sediments have been subjected to only one main period of deformation.

CLEAVAGE

Cleavage is almost totally absent in sub-areas (i) and (ii), with only local development of a rough fracture cleavage in the Kinglake Anticlinorium.

However, cleavage is well developed in sub-area (iii), as shown in Fig. 7. In the tight folding of the Clonbinane district, a rough, near-vertical cleavage is present in both anticlines and synclines, and strikes approximately 110°, making an angle of up to 30° with the axial planes of the folds.

Progressing to the E., strong cleavage occurs near the axes of the major synclines. This cleavage is of the true slaty type where the original rock was a fine siltstone or mudstone, but is not well developed in the thin interbedded sandstones where fracturing radial to the anticlinal axes prevails. The cleavage is either vertical or dips at no less than 70° away from the synclines, the strike often making an angle of about 10° with the fold axes, especially in the E. of the sub-area. Due north of the Mt Disappointment Granodiorite essentially axial plane cleavage is present, agreeing with the idea of simple compression along an azimuth of 28° suggested by the joint analysis. However, the deviation from axial plane cleavage to the E. and W. is possibly significant with regard to the origin of the unusual fold trend in sub-area (iii).

The restriction of the cleavage to the synclines and tension to the anticlines has been noted elsewhere. Junner (1913) observed that in the Diamond Ck district a few miles N. of Melbourne, the synclines were zones of compression, with crumpling and overthrusting, while the anticlines had been subjected to tension at some stage, when quartz veins were intruded.

Although cleavage is not developed in the Yan Yean district, the presence of boudinage in sandstones indicates that locally the sediments have undergone great compression, fine sandstone laminae in the mudstones giving evidence of flowage around the sandstone boudins.

Origin of the Fold Structures

There are three unusual fold structures developed in the area investigated: the major structure is the broad sweep of the folds through 92°, from an average trend to 26° at Yan Yean to 118° at Reedy Ck; secondly, the sharp bend in the Merriang Syncline and Whittlesea Anticline S. of Clonbinane; thirdly, the Kinglake Basin containing, amid regional tight folding, a wide expanse of unfolded sediments.

THE ARCUATE FOLD PATTERN

From Melbourne N. to Yan Yean, the trend of the folded bedrock is about N. 30°E. (Fig. 10). In the Tallarook-Seymour district the fold trend is also roughly meridional, so the regional trend may be taken as approximately N.-S., from which the folding of the Reedy Ck-Flowerdale district deviates.

As described above, the folds of the Melbourne-Yan Yean district (plotted in part from records at the Geology Department) are closely spaced, most not persisting for a great distance along the strike, while in the Reedy Ck-Flowerdale district the folds are about 2 miles apart and continue for many miles. The simple joint patterns obtained throughout the area investigated, and the general lack of cross-folding indicate that all the folds were formed during one main period of deformation. The only possible explanation for the arcuate fold pattern is that the sediments were subjected to a large scale sinistral rotation during regional compression from the E. and W. The probable cause of this rotational force is described below in the light of previous experimental work.

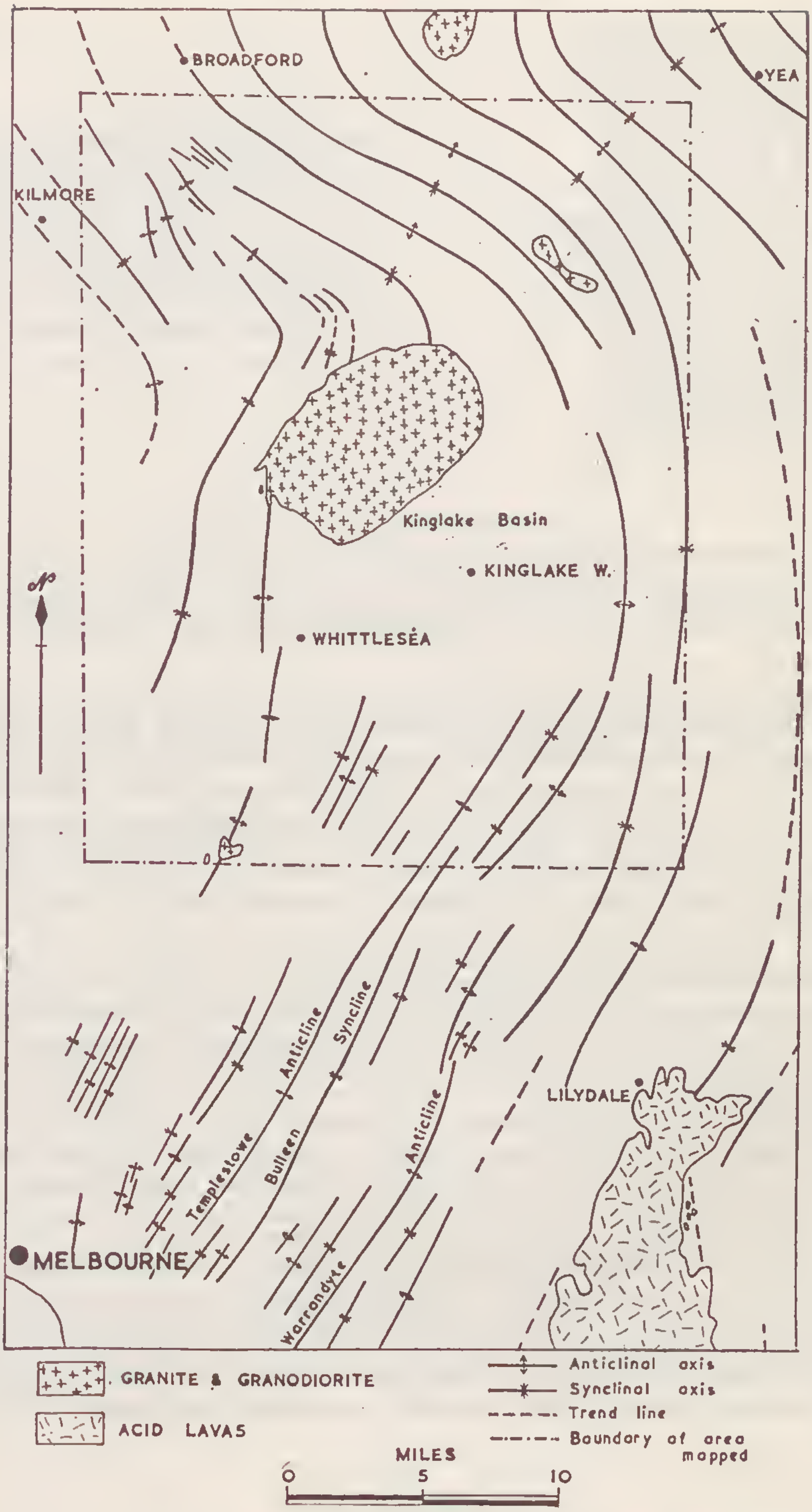


FIG. 10—Structural Map of the Silurian and Lower Devonian Sediments of South-Central Victoria.

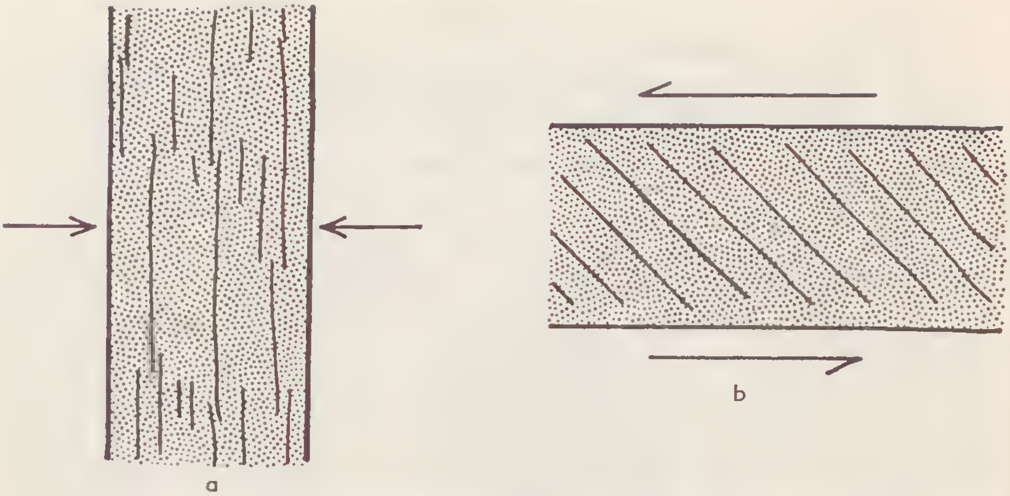


FIG. 11—Formation of folds in paraffin wax:

a. Under direct compression, an overlapping series of plunging folds is produced at right angles to the direction of compression.
b. Horizontal shearing produces a series of elongated folds making an angle of approximately 45 degrees with the direction of shear. (After Mead 1920)

Mead (1920) conducted a series of experiments on the fold patterns produced in layers of paraffin wax subjected to compression, torsion and shearing. He found that overlapping series of folds were produced by compression (Fig. 11a)—wherever a fold terminated by plunging, another fold appeared *en echelon* continuing the necessary amount of shortening. He concluded that plunging folds did not necessarily mean cross-folding, but that they could be 'developed in flat-lying beds, with perfectly even application of shortening stresses'. Mead also found that long, plunging folds parallel to the direction of elongation were caused by shear or rotational stress (Fig. 11b).

Brown (1928a) studied the folds formed when two adjacent wooden blocks covered with alternating layers of paraffin and vaseline were moved laterally with respect to each other. In the experiment where paper was used as the middle layer, folds, and thrust-, shear-, and normal-faults were produced. The long axes of the while the strike of the normal faults was parallel to the short axis of the strain ellipsoid, and formed an angle of 45° to the strike of the underlying shear zone, while the strike of the normal faults was parallel to the short avis of the strain ellipsoid. The folds were 3 to 5 times as long as they were wide, in spite of the fact that they were truncated by normal faults. Brown concluded that 'horizontal movement along buried faults may result in the development of shear faults or folds, and tension- and thrust-faults, the folds being greatly elongated . . .'.

In Mead's experiments, the overlapping folds due to direct compression may be compared with the fold pattern of the Melbourne-Yan Yean area, while the elongated folds due to rotational stress are similar to those of the Reedy Ck-Flowerdale district. Brown's experiment with shearing also produced a fold pattern similar to that at Flowerdale, and suggests a mechanism for the development of this anomalous trend. His conclusion that such basement movements may occur in nature is supported by Moody and Hill (1956) who, in a summary of the world's major wrench faults state, p. 1215, that 'the result of movement along these deep faults can be expressed in the overlying sedimentary veneer more commonly by a complex zone of wrench faults and generally complicated structure than by an individual fault trace. Some deep-seated wrenches appear to be indicated at the surface only by systems of small *en echelon* faults or anticlines'.

Thus, it is likely that the overlapping folds of the Melbourne-Yan Yean district are due to direct compression along a line striking approximately E. 30°S., while the elongated NW.-trending folds of the Flowerdale district were probably caused by drag from a basement sinistral wrench fault or shear zone, running roughly E.-W. between the Mt Disappointment and Trawool granite massifs. The only recognized major fractures or faults within the area investigated—those of the diorite dykes and the linear SE. boundary of the Mt Disappointment Granodiorite—all have a north-easterly trend, and are possibly analogous to the normal faults of Brown's experiment. The deviation of cleavage from the axial planes of the folds in the Clonbinane district suggests that the folds due to the basement movement post-date, in part, those due to E.-W. compression, although both were almost certainly connected with the same orogenic phase.

In Brown's experiment the drag folds made an angle of 45° with the shear plane. Moody and Hill defined γ as the angle between a basement wrench fault and the overlying drag folds, stating that 'the value of the critical angle γ has not yet been determined satisfactorily; generally it varies between 5° and 30°, with an average value of 15°. However, in some instances γ is apparently 0°, and the drag folds, in this situation called compression ridges, are parallel to the parent wrench fault.' Thus, it seems unlikely that a value of γ as high as 45° occurs in nature, and here the basement shear zone N. of Kinglake is considered to run E.-W., giving γ a value of 28° at Reedy Ck. Further evidence supporting this direction for the basement movement will be given below.

The Bend in the Merriang Syncline, Clonbinane

The Merriang Syncline, extending for over 15 miles along the W. margin of the area investigated, undergoes several changes of trend, the most notable being the sharp bend just S. of Clonbinane. Such a bend is unusual for the Silurian sediments of Victoria, and may be termed 'axial plane folding' (Scotford 1956).

Scotford postulated compression from two different directions to account for axial plane folding in the metamorphic rocks of New York. However, as mentioned above, there is no evidence for cross-folding in the Kinglake district. If the bend were due to a direct thrust from the W., overfolding to the E. would be expected, but as the axial plane of the Merriang Syncline is here inclined to the W. this manner of formation of the bend also appears unlikely. Thus it seems probable that the sharp bend was caused by the same sinistral rotation that produced the anomalous fold trend of the Reedy Ck-Flowerdale district.

The Kinglake Basin

The third unusual feature of the folds within the area mapped is the Kinglake Basin, containing nearly 100 square miles of low-dipping beds and intruded in the NW. by the Mt Disappointment Granodiorite.

The Ordovician rocks of Central Victoria are very tightly folded, with widespread development of slates, but the Silurian sediments show little or no cleavage. However, there is no marked difference in structure between sediments of Lower and

Upper Silurian age in the Melbourne district, so a sudden decrease in fold intensity in sediments of Upper Ludlovian age does not seem likely. The sediments of the Humevale Formation in the Clonbinane-Reedy Ck district are just as tightly folded as those of the Yan Yean Formation, while the Lower Devonian sediments of the Lilydale district are strongly folded, with dips up to 70° (Gill 1942, p. 28). Thus, although there may well be a slight decrease in fold intensity from the Silurian to Lower Devonian sediments of Central Victoria, it does not seem sufficent alone to account for the formation of the Kinglake Basin.

The Kinglake Basin appears to be similar to the 'geosynclinettes' in the Eastern Geosyncline, New Zealand (Kingma 1958), which are basins from 15 to 20 miles long by 6 to 10 miles wide, containing up to 15,000 ft of sediments. Kingma, p. 270, stated that the geosynclinettes 'have been large enough to act as obstacles to the regional folding, and although they have been tilted, they have rarely suffered internal folding'. The close relationship between joint pattern and fold trend indicates that the massive siltstones of the Kinglake Basin have undergone compression, and it is probable that these sediments, in part at least, also resisted the regional folding. Such an origin for the Kinglake Basin is supported by Hills's (1945) observation that 'gliding along laminae. . . goes far toward accounting for the frequent development of close and acute folds in thin bedded rocks, as compared with broader and more open folds in massive strata'.

Structure of Central Victoria

Thomas (1939, 1958) made brief reference to the arcuate and persistent folds in the Silurian and Lower Devonian sediments between the Heathcote and Mt Wellington Cambrian belts in Central Victoria. He noted that the curves seemed to have their centre somewhere near Melbourne, but offered no explanation as to their origin.

Fig. 12 shows the structure of the Lower Palaeozoic rocks of Central Victoria. The map is based on Thomas (1939), but the structure of the Silurian and Lower Devonian has been much supplemented with recent work, and also by data in old mining reports. Three major fold arcs, all of similar sense, are present, most clearly shown at Kinglake, Heathcote and Rushworth. The arcuate folds continue E. from Kinglake, the strike gradually changing from 118° at Reedy Ck to 160° in the Walhalla Synclinorium; N. of the Cobaw Massif, the thrust-faulted Heathcote Axis and adjacent sediments make a large inflection to the W.; another great arc extends eastwards from Rushworth, the strike increasing from 100° at Rushworth to approximately 130° at Benalla. It is noteworthy that the Cambrian belts generally follow these trends.

Numerous experiments were carried out in an attempt to determine the mechanisms of formation of the various fold patterns present in Central Victoria.

EXPERIMENT 1: Folds due to simple compression.

A rubber strip about 5 in. wide and 18 in. long was stretched over a flat wooden board and firmly secured by pins. Soft grease was then spread over portion of the rubber, a thin tissue paper placed on the grease and the surface smoothed. The pins were then removed, and the rubber allowed to slowly contract.

The resultant close, overlapping folds (Pl. L, fig. 1) are similar to those produced under simple compression by Mead (1920), and may be compared with the fold pattern of the Yan Yean-Melbourne district. The folds in Pl. L, fig. 1 are rarely parallel for long and often, where *en echelon* displacement occurs, there is

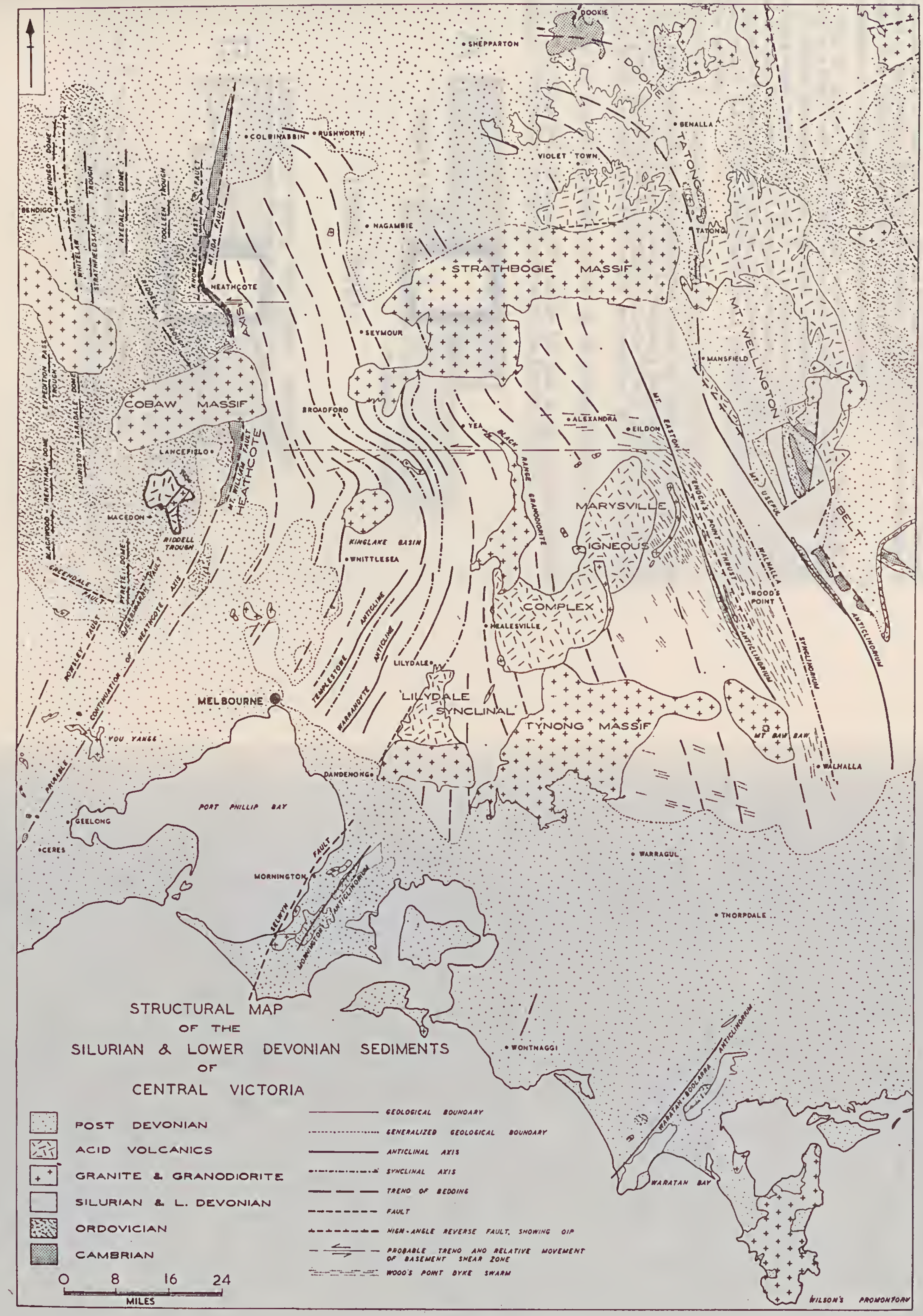

STRUCTURAL MAP
OF THE
SILURIAN & LOWER DEVONIAN SEDIMENTS
OF
CENTRAL VICTORIA
POST DEVONIAN
ACID VOLCANICS
GRANITE & GRANODIORITE
SILURIAN & L. DEVONIAN
ORDOVICIAN
CAMBRIAN
GEOLOGICAL BOUNDARY
GENERALIZED GEOLOGICAL BOUNDARY
ANTICLINAL AXIS
SYNCLINAL AXIS
TREND OF BEDDING
FAULT
HIGH-ANGLE REVERSE FAULT, SHOWING DIP
PROBABLE TREND AND RELATIVE MOVEMENT OF BASEMENT SHEAR ZONE
WOOD'S POINT DYKE SWARM
0
8
16
24
MILES
DOOKIE
SHEPPARTON
DOOKIE
BENALLA
TATONG
TATONG
VIOLET TOWN
COLBINABBIN
RUSHWORTH
NAGAMBIE
BENDIGO
BENDIGO DOME
WHITELAW FAULT
STRATHFIELDSAYE TROUGH
AXEDALE DOME
TOOLLEEN TROUGH
KNOWSLEY EAST FAULT
MT. IDA FAULT
HEATHCOTE
AXIS
STRATHBOGIE MASSIF
MT. WELLINGTON
MANSFIELD
SEYMOUR
EXPEDITION PASS TROUGH
LAURISTON - TARADALE DOME
BLACKWOOD - TRENTHAM DOME
RIDDELL TROUGH
COBAW MASSIF
BROADFORD
ALEXANDRA
EILDON
MT. EASTON
ENOCH'S POINT THRUST
MT. USEFUL
BELT
LANCEFIELD
MT. WILLIAM FAULT
HEATHCOTE
YEA
BLACK RANGE GRANODIORITE
MARYSVILLE
IGNEOUS
COMPLEX
MACEDON
RIDDELL TROUGH
KINGLAKE BASIN
WHITTLESEA
GREENDALE FAULT
PYRETE DOME
CAMPASPE FAULT
HEATHCOTE AXIS
HEALESVILLE
WOOD'S POINT
WALHALLA
ANTICLINORIUM
SYNCLINORIUM
ANTICLINORIUM
TEMPLESTOWE ANTICLINE
WARRANDYTE ANTICLINE
LILYDALE
ROWSLEY FAULT
CONTINUATION OF HEATHCOTE AXIS
MELBOURNE
LILYDALE SYNCLINAL
TYNONG MASSIF
MT BAW BAW
WALHALLA
YOU YANGS
PROBABLE
DANDENONG
PORT PHILLIP BAY
GEELONG
CERES
WARRAGUL
MORNINGTON
FAULT
SELWYN
MORNINGTON ANTICLINORIUM
THORPDALE
WONTHAGGI
WARATAH - BOOLARRA ANTICLINORIUM
WARATAH BAY
WILSON'S PROMONTORY

FIG. 12

a swing in the trend. Consequently, areas of high fold density also tend to be areas where the folds deviate from the normal trend, and are probably due to inhomogeneity of the medium. These areas appear to be analogous to the crush-zones at Studley Park (Hills 1941) and Warrandyte (Jutson 1911).

EXPERIMENT 2: Folds due to horizontal sinistral shear.

Here the grease and tissue paper were mounted on two flat wooden blocks joined by a tongue and groove and free to move laterally with respect to each other.

A sinistral movement of the top block produced a series of drag folds in the overlying tissue paper (Pl. L, fig. 2). This confirms the work of Brown (1928a), and demonstrates that sinistral basement movement produces a fold pattern similar to that of the Flowerdale district. The folds shown here differ from those of Brown's experiment in that they are sigmoidally curved, probably due to drag in the softer grease medium.

EXPERIMENT 3: Compression followed by horizontal sinistral shear.

The two wooden blocks described above, grease and tissue paper were used. The 'N.-S.' folds (Pl. L, fig. 3) were formed by stretching the tissue paper lengthwise, as the soft grease did not allow the formation of even folds by pushing from the sides. The top block was then moved to the left, producing an 'E-W.' basement sinistral shear.

There are several noteworthy features of the resultant fold pattern (Pl. L, fig. 4).

1. The sharp bend of almost 90° on the left side of the stationary block is analogous to the sudden change of trend within the Kinglake district.

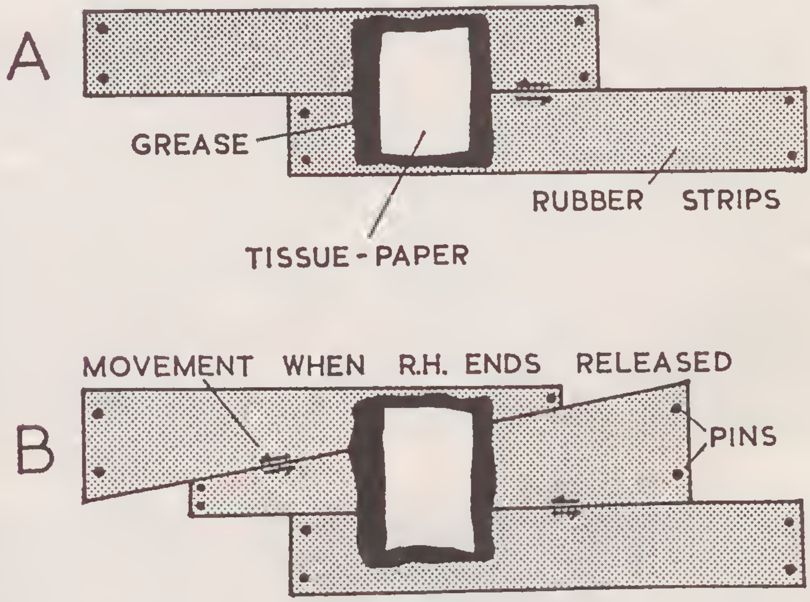


FIG. 13—a. Two stretched rubber strips arranged to produce simultaneously both compression and 'E.-W.' shear.
b. Three rubber strips arranged to produce simultaneously compression and two non-parallel shears.

2. The angle γ between the drag folds and the underlying shear increases from about 30° on the left to 50° on the right. Similarly, the folds at Reedy Ck strike approximately 120°, and in the Yea-Eildon district 150°-160°.

3. In the lower block the arcuate folds are not concentric and the radii of curvature increase to the right, as with the folds from Kinglake to the Walhalla Synclinorium.

EXPERIMENT 4: Simultaneous compression and horizontal sinistral shear.

Two strips of rubber each about 5 in. wide and 18 in. long were equally stretched and pinned side by side to a wooden board, with the lower strip displaced to the right (Fig. 13a).

Grease and tissue paper were applied across the two strips, the right hand ends released and both strips allowed to slowly contract. Although contraction was everywhere the same, the staggered positions caused lateral movement between the strips similar to that of a sinistral wrench fault.

The fold pattern produced by this simultaneous compression and shearing is shown in Pl. L, fig. 5. The angle γ and the radii of curvature of the fold arcs increase to the right as in experiment 3, and again compare with the folding in South-Central Victoria. The folds due to compression are small and overlapping, grading into the stronger, more persistent folds across the shear in analogous manner to the folds of the Kinglake district. Also, the folds on the left hand side are asymmetrical with axial planes inclined to the left, comparable with the asymmetry of the Merriang Syncline and the overfolding to the W. in the Heathcote Junction district. In the centre the folds are mostly symmetrical, while on the right the axial planes dip to the left.

EXPERIMENT 5: Compression with two horizontal sinistral shears.

Firstly, three rubber strips were stretched in staggered position to produce simultaneously both compression and two 'E.-W.' sinistral basement shears. The lower shear produced a fold pattern similar to that of the Kinglake-Eildon-Walhalla arc, but in no experiment was it possible to reproduce the E.-W. folds of the Rushworth district, no matter how far the top rubber strip was displaced to the left.

The trend of the upper shear was then altered from E.-W. to a strike of about 77° as shown in Fig. 13b, Pl. L, fig. 6 being typical of the fold patterns produced. The angle γ, although it increases to the right, is approximately the same for each shear, being about 30° on the far left. Consequently, on the left, the upper set of drag folds strikes approximately 107°, and the lower set 120°, consistent with the fold trends at Rushworth and Flowerdale respectively. Altering the strike of the upper shear to 65° would no doubt produce folds striking almost E.-W. The lateral variations in radii of curvature and angle γ of the drag folds result in much sharper changes of trend on the left, analogous to the sharp bends in the folds of the Kinglake and Rushworth districts.

CONCLUSIONS FROM EXPERIMENTAL WORK

Experimental evidence supports the theory that the arcuate folds of South-Central Victoria were caused by sinistral movement along a basement shear zone trending approximately E.-W., and extending from Kinglake to the Walhalla Synclinorium (see Fig. 12). Such a shear zone would be parallel to the linear S. boundaries of the Strathbogie Granite Massif, which probably represent pre-granite faults.

It is possible that the Heathcote inflection is due to another, but much smaller basement shear zone, again showing sinistral movement and running E.-W. This shear zone would be aligned with the main linear S. boundary of the Strathbogie Granite, and possibly major basement movement exists along this line.

Experimental evidence also shows that sinistral movement along a basement shear zone striking between 65° and 75° could have produced the Rushworth-Benalla fold arc. Such a shear zone would be roughly parallel to a number of major Palaeozoic faults in the Beechworth-Kiewa area to the E., shown on the Tectonic Map of Australia.

THE HEATHCOTE AXIS

The Heathcote Axis (Thomas 1937, 1939) is a narrow, thrust-faulted, submeridional inlier of Cambrian rocks marking the junction of the Ordovician and Silurian sediments of Central Victoria.

Thomas (1939, p. 62) stated that it was 'difficult to trace this belt (the Heathcote Axis) to the south, but it takes a twist to the south-west near Monegeetta and is lost under the basalt of the Keilor Plains'. However, Coulson (1929, 1932) showed that outcrops of diabase at the You Yangs, and at Dog Rocks and Ceres W. of Geelong, would lie on a line produced to the SW. from Monegeetta, and on Fig. 12 it may be seen that this extrapolated line is closely parallel to the fold trend of the Silurian rocks to the E.

Anderson (1951) noted the common association of folds, thrust faults, and wrench faults in deformed sediments, and considered they were formed simultaneously by the same compressive movements. He stated that 'any system of transcurrent faults should theoretically consist of two classes, whose members are complementary, and run in different directions. There may thus be four different types of structure in one area (folds, thrust faults, to transcurrent faults) which are evidently connected, but this association is seldom complete. In much of the Jura Mountains, and of the Scottish Highlands, only one of the two possible sets of transcurrent faults has been established . . .'.

The probable association between basement wrench faults and the folds of the Victorian Siluro-Devonian sediments has been indicated above, with only one of the two posible sets of wrench faults, those with sinistral movement, having developed. However, Hills and Thomas (1954) stated that during the Ordovician, the major anticlinal structures, such as the Heathcote Axis, 'were already developing as geanticlines within the trough, with thinner deposits forming on them . . .', suggesting that the Heathcote Axis was a major structure prior to the folding of the Tabberabberan Orogeny. Sinistral movement beneath the Silurian and Lower Denovian sediments would mean that, to the N., the basement blocks would be thrust progressively more to the W., possibly causing re-faulting along the axis, the relative movement being 'E. block under' rather than 'W. block over'. Such re-faulting would give the Heathcote Axis faults their greatest stratigraphic throw to the N., which is the actual case.

Thus, it seems likely that at the time of folding of the Silurian and Lower Devonian sediments of Central Victoria, the basement was divided into several large blocks by E.-W.-trending fractures or faults, while the major structural line of the Heathcote Axis was already partly developed. Following initiation of the folding by compression acting along an azimuth between 90° and 120°, sinistral movement between several of the basement blocks caused arcuate folds in the overlying sediments and deflection and re-faulting of the Heathcote Axis. The boundaries of the Strathbogie Granite were possibly later controlled by some of these basement fractures.

Igneous Rocks of the Kinglake District

DIORITES

At least 6 dykes and 2 stocks of quartz diorite intrude the sediments of the Kinglake district (Fig. 2). These were hard to map accurately owing to their deeply weathered state, so old mine diggings and reports proved very useful. Consequently there may be many undiscovered dykes within the area, particularly in the heavily timbered country.

1. Reedy Ck Quartz Diorite Dyke:

Murray (1884), who was first to record the presence of this dyke, considered it to be 50 to 200 ft wide and to run NE. from Sunday Ck to Strath Ck. However, 3 separate diorite dykes are present in this district, the largest being approximately 2 miles in length, striking 73°, about 3 miles S. of Reedy Ck. Murray reported that the dyke was locally intersected by auriferous quartz veins extending from wall to wall, which were worked for gold and antimony.

The dyke is a fine-grained, greenish, mesocratic rock, thin sections revealing that it has undergone extensive alteration. The least altered (Section 8499) contains large euhedral and occasionally twinned phenocrysts of green-brown hornblende, partially altered to chlorite. No cores of augite or enstatite were observed in the hornblende, although Edwards (1937, p. 98) noted the feature in this dyke. The groundmass consists of zoned plagioclase, probably andesine, the cores having been extensively altered to sericite, cloudy orthoclase, and interstitial quartz. Accessory minerals include ilmenite, apatite, sphene, and epidote.

In the more altered rock (Sections 8500, 8501) the hornblende is represented almost entirely by pseudomorphs of chlorite, often in large, irregular patches. Most of the felspar is very cloudy and of low refractive index, with occasional lamellar twinning suggesting some is albite. Epidote is common and fibrous tremolite has

TABLE 3

Chemical Analyses of Quartz Diorites

	(1)	(2)	(3)	(4)
SiO_2	54·66	53·60	52·53	49·65
Al_2O_3	18·05	16·28	18·78	16·73
Fe_2O_3	1·06	0·44	1·52	0·31
FeO	7·04	10·34	6·60	8·99
MgO	6·21	6·80	3·02	5·88
CaO	1·20	7·10	7·21	7·87
Na_2O	4·77	2·80	2·54	3·10
K_2O	2·64	1·70	1·73	0·80
H_2O+	3·48	0·44	2·24	2·50
H_2O-	0·26	0·15	0·53	0·14
CO_2			0·39	1·08
P_2O_5			0·32	0·04
MnO			0·14	0·14
TiO_2	1·15	1·14	2·16	2·81
	100·52	100·79	99·71	100·04

(1) Reedy Ck quartz diorite. (Analyst: V. Biskupsky)
(2) Mt Robertson quartz-hypersthene diorite. (Analyst: V. Biskupsky)
(3) St Andrews quartz diorite. (Analyst: N. R. Junner)
(4) Morning Star dyke, Wood's Point. (Analyst: A. W. Howitt 1887)

developed locally in radial clusters. Other common accessory minerals are sphene, leucoxene, pyrrhotite, pyrite, and apatite. Interstitial quartz is widespread, often in granophyric intergrowth with felspar.

A chemical analysis of the dyke rock is shown in Table 3, No. 1, together with an analysis of the Morning Star dyke, Wood's Point. The low percentage of lime and the high percentage of water in the Reedy Ck diorite are probably due to leaching of calcium carbonate, none of which was observed in thin section. Otherwise, the chemical composition is similar to the Wood's Point dyke.

2. Clonbinane Quartz Diorite Dyke:

The Clonbinane diorite dyke is at least 1½ miles long, striking 80° across Sunday Ck, and according to Whitelaw (1899) averaging about 80 ft in width. The rock is fine-grained and greenish, with a large amount of pyrite and arsenopyrite disseminated throughout, while towards the NE. it tends to be porphyritic. Sections 8502 and 8503 show that the dyke is a typical propylitized quartz diorite, containing irregular pseudomorphs of chlorite; partially chloritized hornblende; cloudy twinned felspar, probably albite; interstitial quartz; ilmenite grains; with alteration products pyrite, leucoxene, calcite, and epidote.

Whitelaw (1899) and Jenkins (1902) both noted that mineralized reefs composed of quartz, stibnite, pyrite, and breccia of the Silurian rocks cross the dyke at right angles every few yards, dying out a foot or so beyond the dyke. These reefs vary from 12 ft to a few inches in width, generally the wide spaces being filled with quartz and the narrow spaces with stibnite.

3. Tunnel Hill Dykes:

A large, weathered dioritic dyke, striking approximately 55°, is exposed in old mines and tunnels at Tunnel Hill, about 4 miles N. of the Mt Disappointment Granodiorite. Granodiorite porphyrite (Section 8504) occurs as float in Strath Ck, near Tunnel Hill, although it was not observed in situ.

4. Yow Yow Quartz Diorite:

About 1½ miles E. of St Andrews is an elliptical shaped intrusion of quartz diorite about ¼ mile long and trending approximately NE. This has been described in detail by Junner (1914), and a chemical analysis of the rock is included in Table 3.

5. Mt Robertson Quartz-Hypersthene Diorite:

A small, oval-shaped intrusion of diorite about ½ mile long and trending NE. occurs near Mt Robertson, 5 miles NE. of Kinglake West. The intrusion, which is deeply weathered, is almost completely surrounded by a narrow aureole of quartz-sericite-biotite hornfels, indicating that the adjacent siltstones have undergone low-grade thermal metamorphism.

The rock is medium to fine grained, mesocratic and slightly greenish when fresh. Sections 8506 to 8508 contain small tabular phenocrysts of twinned andesine partly altered to sericite, and occasionally zoned augite, enstatite and hypersthene. A few of the pyroxenes have been partially altered to a green, fibrous hornblende and sericite?; pseudomorphs of hornblende are probably after pyroxene. Biotite is interstitial to the felspar and pyroxene phenocrysts, occasionally forming jackets around the hypersthene and hornblende. Cloudy orthoclase and interstitial quartz are also present, with accessories iron ore, apatite, and zircon. The biotite rims to the hypersthene are similar to those noted by Edwards (1932b) in unmetamorphosed hypersthene dacites of the Warburton area, and ascribed by him to reaction between hypersthene and orthoclase.

The rock may be classified as a quartz-hypersthene diorite, and is petrologically similar to the hypersthene porphyrite at Tooborac (Singleton 1949). The chemical analysis is given in Table 3, No. 2.

6. Upper Plenty Dykes:

A road cutting ¼ mile E. of the North Eastern Railway (grid reference 061,869 Kinglake Military Map) exposes a dioritic dyke about 150 ft wide and striking 50°. The sedimentary rocks adjacent to the dyke are highly jointed and rubbly, having the appearance of weathered hornfels. Owing to its highly weathered state it was not possible to trace the dyke far.

A small weathered dyke, probably a porphyritic diorite, about ¼ mile long and averaging about 10 ft in width, occurs on a hill ½ mile N. of the Wallan Road, Upper Plenty (grid reference 091,850 Kinglake Military Map). The dyke strikes 25° parallel to the trend of the Silurian strata, bulging to a width of 60 ft at its NE. end.

E. of Upper Plenty, numerous fresh boulders of a porphyritic quartz diorite (Section 8509) are common at Conical Hill (grid reference 115,838 Kinglake Military Map). Another porphyritic dyke in this vicinity is recorded on the Quarter Sheet No. 4 SE., but neither has been traced far due to the thick soil and timber cover.

7. Steel's Ck Quartz-Felspar Porphyry:

At Steel's Ck in the SE. corner of the area mapped is an irregular shaped intrusion of quartz-felspar porphyry containing N.-trending veins of quartz and stibite (Whitelaw 1899, Threadgold 1958). The porphyry, which shows signs of intense shearing, is part of a larger intrusion extending beyond the area mapped.

AGE OF THE DYKES

It has been shown that within the Kinglake district there are a number of diorite dykes and 'dyke-bulges' which, in their petrology, chemical composition, alteration, structure, and mineralization, closely resemble those of the Wood's Point dyke swarm to the E.

Hills (1952) gave the age of the Wood's Point dyke swarm as late Middle or early Upper Devonian stating, p. 89, that 'the upper age limit to the swarm is afforded by its relationship to the Upper Devonian sedimentary and volcanic rocks of the Marysville Complex, which the dykes do not penetrate'. A similar age is likely for the diorites of the Kinglake district, and they probably pre-date the Mt Disappointment and other granodiorite intrusions.

Fig. 12 shows that the dykes of the Wood's Point swarm trend north-westerly at Walhalla, parallel to the regional strike of the folded sediments, but N. of Walhalla swing gradually to the W. until at Alexandra the trend is E.-W. All the diorite intrusions within the Kinglake district have a north-easterly trend, and possibly form a continuation of the arc W. of Alexandra.

GRANODIORITES

FLOWERDALE MICROGRANODIORITE

The microgranodiorite intrusion at Flowerdale is dumb-bell shaped, approximately 3 miles long with a maximum width of 1 mile, and lying parallel to the fold trend of the district. Two quartz porphyry dykes each at least 1 mile in length extend from the two main lobes of microgranodiorite, making the intrusion as a whole arcuate in outline. Both Break-o'-Day Ck and King Parrot Ck cross the microgranodiorite, which is deeply weathered and mostly covered with stream alluvium.

Contact Metamorphism:

The microgranodiorite is surrounded by a prominent aureole of thermally metamorphosed sediments, most strongly developed on the NE. side.

The siltstones approximately ½ mile from the contact have a spotted texture, while closer to the microgranodiorite a dark blue, tough hornfels is developed. Most of the inner zones of the aureole consist of quartz-biotite-sericite or quartz-biotite-muscovite hornfels. Section 8510 contains unaltered detrital quartz grains, although the chloritic groundmass has recrystallized into a fine intergrowth of biotite and sericite. At higher grades of metamorphism the hornfels is composed of anhedral, interlocking quartz grains and abundant laths of biotite and muscovite arranged in decussate texture, as shown in Section 8511 from Flagpole Hill. Other minerals include rare orthoclase, iron ore, apatite, and chlorite after biotite.

A true cordierite hornfels is present about ¼ mile from the contact 1 mile S. of the Three Sisters. Section 8512 contains anhedral porphyroblasts of cordierite poikiloblastically enclosing quartz, iron ore, muscovite, biotite, and fine rutile (?) needles. Between the cordierite porphyroblasts is a mosaic of quartz and rare orthoclase, biotite and muscovite laths, and iron ore.

Quartz Porphyry Dykes:

S. of the Three Sisters a conspicuous gully in the aureole marks the position of a quartz porphyry dyke about 15 ft wide which extends for over a mile to the NW. The hornfels is brecciated near this gully, and the dyke is greatly fractured and shows evidence of shearing.

The porphyry is fine grained and cream to pink in colour. Samples farthest from the microgranodiorite (Section 8514) contain rectangular to sub-rounded phenocrysts of quartz; phenocrysts of orthoclase now largely represented by pseudomorphs of sericite and kaolin?; and a microcrystalline groundmass of quartz, orthoclase, sericite, and occasional iron ore grains. However, at the contact (Section 8515) the felspar phenocrysts show little alteration to sericite and have a refractive index very close to that of the medium, suggesting they are of albite. Subhedral quartz phenocrysts and ragged plates of muscovite enclosing numerous rounded quartz grains are also present, while the groundmass of quartz and felspar is coarser grained than in Section 8514. These differences suggest that the dyke has been slightly metamorphosed by the microgranodiorite.

Another quartz porphyry dyke about 20 ft wide has been traced for nearly a mile to the S. from Flagpole Hill. Again the dyke is sheared, similar in appearance to that at the Three Sisters, except for occasional flakes of biotite 1-2 mm in diameter. Section 8516 taken from the S. end of the dyke contains phenocrysts of quartz, orthoclase, and biotite set in a fine-grained groundmass of orthoclase laths, sericite, biotite, and interstitial quartz. Section 8517 from near the microgranodiorite has similar quartz phenocrysts to Section 8516, but biotite phenocrysts are more numerous and tend to be ragged in outline. Small muscovite flakes in decussate arrangement are abundant, while muscovite and biotite, often in radial clusters, partly replace the orthoclase phenocrysts. The groundmass tends to be granulitic, with fewer felspar laths than in Section 8516. These changes suggest that this quartz porphyry dyke also has been slightly metamorphosed, but are not sufficient alone to indicate that the quartz porphyry dykes pre-date the microgranodiorite.

Several other quartz porphyry dykes are present within the area mapped, e.g. Section 8518 from a creek about 4 miles S. of Flowerdale.

Microgranodiorite:

The microgranodiorite is a fine-grained, mesocratic rock similar in appearance to a dacite, with individual crystals seldom exceeding 1·5 mm in diameter.

Section 8519 shows that the rock has the typical hypidiomorphic texture of a granodiorite, containing euhedral to subhedral andesine and oligoclase, both twinned and zoned, with the cores often altered to sericite and calcite; slightly cloudy orthoclase, with numerous inclusions of quartz and micas; ragged laths of dark-brown biotite containing many pleochroic haloes and often extensively altered to a pale-green chlorite; slender laths of muscovite, often arranged in radial pattern; interstitial quartz, and scattered grains of iron ore. Section 8520 from near the contact at the Three Sisters is rich in orthoclase, euhedral prisms of brown tourmaline indicating pneumatolytic action.

TABLE 4

Chemical Analyses of Granodiorites

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
SiO_2	65·88	69·17	66·30		66·90	67·80	66·13	67·75
Al_2O_3	14·61	15·95	16·42		15·75	15·63	16·83	16·11
Fe_2O_3	0·85	0·88	0·52		0·75	0·48	1·11	0·50
FeO	4·15	3·64	3·00		3·95	3·56	4·17	4·00
MgO	2·74	1·12	1·05		0·38	0·23	1·83	0·79
CaO	1·45	3·04	1·85		3·30	2·14	3·26	2·68
Na_2O	3·23	2·64	2·65	1·99	3·88	3·80	2·25	2·60
K_2O	5·10	3·07	6·00	5·19	3·80	5·18	3·14	3·42
TiO_2	0·85	0·77	0·44		0·66	0·53	trace	0·85
H_2O+	1·11	0·36	0·42		0·43	0·54	1·91	1·16
H_2O-	0·23				0·06	0·09		
MnO		0·03	0·05				0·07	trace
P_2O_5		0·02	1·12				trace	0·09
Total	100·20	100·69	99·82		99·86	99·98	100·70	99·95

(1) Flowerdale Microgranodiorite. (Analyst: V. Biskupsky)
(2) Quarry Hill Granodiorite, South Morang. (Analyst: F. J. Watson)
(3) Porphyritic marginal phase, South Morang Granodiorite. (Analyst: A. B. Edwards)
(4) Metamorphosed Silurian shale adjacent to porphyritic granodiorite, South Morang.
(5) Non-porphyritic outer phase, Mt Disappointment Granodiorite. (Analyst: V. Biskupsky)
(6) Porphyritic inner phase, Mt Disappointment Granodiorite. (Analyst: V. Biskupsky)
(7) Bulla Granodiorite. (Analyst: F. J. Watson) (James 1920)
(8) Mt Gellibrand 'Adamellite', Broadmeadows. (Analyst: H. C. Richards) (Stillwell 1911)

A chemical analysis of the microgranodiorite (Table 4, No. 1) shows that although it is richer in potash and magnesia, and poorer in lime than other granodiorites from south-central Victoria, it has much in common with these rocks. The higher potash and magnesia contents are possibly due to the great amount of biotite in the microgranodiorite.

The fine grain and elongated shape of the microgranodiorite suggest that it is not the top of a typical stock, but tends more towards a large dyke, similar to the arcuate microgranodiorite dyke at Tooborac (Singleton 1949). The stronger aureole on the NE. side may be due to the microgranodiorite dipping to the NE., but there is no evidence available to support this.

MORANG GRANODIORITE

The Morang Hills, composed of a small granodiorite stock and associated metamorphosed Silurian sediments, form an inlier about 4 miles long and 3 miles wide in the Newer Basalt flows S. of Whittlesea.

The petrology of the igneous and metamorphic rocks has been described in detail by Edwards and Baker (1944). Portion of the E. margin of the granodiorite contains many anhedral perthite phenocrysts up to 3 in. long; a chemical analysis of this porphyritic phase (Table 4, No. 3) shows that it is distinctly richer in potash and phosphorus, and poorer in lime, than the normal granodiorite (Table 4, No. 2), but otherwise both phases are similar. Edwards and Baker considered that the enrichment of potash was due, in part at least, to assimilation of country-rock because of 'the abundance of xenocrystic matter in the marginal phase, and the established potassic character of the adjacent contact sediments' (Table 4, No. 4).

MT DISAPPOINTMENT GRANODIORITE

The Mt Disappointment Granodiorite is a small, oval-shaped massif about 8 miles long (NE.-SW.) and 5 miles wide, lying almost entirely within the Kinglake Basin and forming the most elevated country in the Kinglake district. The intrusion is surrounded by a prominent metamorphic aureole, although the exact contact with the country rock was difficult to map due to the thick soil and vegetation cover. Two distinct, roughly concentric phases are present in the granodiorite—the outer of medium grained granodiorite, and the inner of slightly coarser grain containing abundant large perthite phenocrysts.

Contact Metamorphism:

The aureole of thermally metamorphosed sediments is generally about ¾ mile wide, increasing to 1½ miles on the arcuate NE. boundary. Section 8521 taken about ¾ mile from the contact contains oval spots about 0·5 mm in length, composed mainly of a pale green, isotropic material of low refractive index. In the areas between the spots, the argillaceous matrix of the siltstone has recrystallized to a fine intergrowth of biotite and muscovite, although the detrital quartz grains appear unaffected. Nearer the contact, a dark-blue, tough cordierite hornfels has developed (Sections 8522 and 8523). The cordierite occurs as ragged porphyroblasts enclosing rounded quartz and iron ore grains, and flakes of muscovite and biotite, set in a fine-grained mosaic of quartz, biotite, and muscovite. Section 8523 shows the original sedimentary laminations, the sandy bands crystallizing into a coarser grained quartz-biotite-muscovite hornfels containing no cordierite.

The contact metamorphic rocks within the area mapped are all of a similar type, not rising above the grade of cordierite hornfels. Even though a small number of sections from the Mt Disappointment aureole were examined, it is likely that they are representative, as the argillaceous sediments change little either vertically or laterally. The low grade metamorphism of the sediments shows that the granodiorites were intruded under conditions of low temperature and pressure, and a high level of emplacement, similar to that of other Central Victorian massifs, is indicated.

Granodiorite:

Outer Phase. The granodiorite of the outer phase is a mesocratic, medium grained rock, containing no phenocrysts and only occasional xenoliths. Sections 8524 to 8528 consist of zoned and twinned oligoclase (Ab_{80}) partly altered to sericite and calcite; allotriomorphic and interstitial quartz; biotite, locally altered to a pale-green, fibrous chlorite; and orthoclase, often containing streaks of dusty inclusions and exhibiting perthitic intergrowth with albite. Accessory minerals include zircon, giving rise to pleochroic haloes in the biotite; irregular grains of ilmenite; and apatite. A chemical analysis (Table 4, No. 5) shows that the non-porphyritic phase is a typical granodiorite, similar in composition to the granodiorites at Morang, Bulla and Mt Gellibrand (Table 4, No. 2, 7, 8).

Inner Porphyritic Phase. The porphyritic phase is typified by the presence of numerous granitized xenoliths, and abundant rectangular orthoclase phenocrysts up to 4 in. long and 1½ in. wide containing numerous biotite flakes arranged in concetric layers (Pl. LI, fig. 1). The groundmass is a granodiorite, but slightly coarser grained than the outer phase. No actual contact between the two phases was observed, but where exposure was fair the change occurred over 50 yds to ¼ mile.

The groundmass of the porphyritic phase (Sections 8529 to 8533) is composed of quartz oligoclase (Ab_{80}), orthoclase, biotite, numerous large apatite prisms, and alteration products chlorite and sericite. Sections 8529, 8530 and 8531 show the phenocrysts to be of anhedral perthite, often showing Carlsbad twinning, and containing biotite, muscovite, and corroded oligoclase aligned parallel to the c-axis. These inclusions are probably due to the crowding aside of earlier formed tabular minerals during crystallization of the phenocrysts, indicating rapid crystallization in a fluid environment.

A chemical analysis (Table 4, No. 6) shows that the porphyritic phase is considerably richer in potash and poorer in lime than the normal granodiorite (Table 4, No. 5), but otherwise the two are very similar. Such variations were also noted by Edwards and Baker between the porphyritic and non-porphyritic phases of the Morang Granodiorite.

Xenoliths:

Xenoliths, ranging in size from a fraction of an inch to 18 in. in diameter, are common within the porphyritic phase, although rare in the non-porphyritic granodiorite.

In the normal phase the xenoliths tend to be small and round, contain abundant biotite and generally have the appearance of a microgranodiorite. Most commonly (Sections 8534, 8535, and 8536) they are composed of brown biotite, zoned oligoclase, quartz and othoclase, with minor amounts of sericite, chlorite, ilmenite, and apatite. Two sections (8537 and 8538) are composed almost entirely of oligoclase, biotite, and quartz, with little or no orthoclase, while Section 8539 is distinguished by abundant green hornblende, containing also biotite, oligoclase, quartz, and rare orthoclase.

Section 8540 shows the contact between the granodiorite and a dark, dense xenolith. The normal granodiorite changes near the contact to a fine-grained mosaic of andesine crystals containing subhedral to anhedral porphyroblasts of green hornblende. Further into the xenolith, labradorite is the dominant felspar, partly enclosed by large, embayed porphyroblasts of augite and hornblende. Thus, over about ¼ inch, the section shows a range in composition from granodiorite to gabbro.

The ovoid xenoliths of the porphyritic phase are generally larger, lighter coloured and contain less biotite than those of the normal granodiorite, their texture often being fibrous due to numerous fine felspar laths. The most common type (Sections 8541 to 8544) contains large twinned and zoned porphyroblasts of oligoclase and occasionally of quartz, set in a groundmass of slender oligoclase laths, biotite, interstitial quartz, and varying amounts of orthoclase, locally common. Section 8545 is similar except that it contains no large porphyroblasts and a little more orthoclase, while Section 8546 has a more granitic texture, being composed mainly of biotite, oligoclase, quartz, and a generous scattering of sphene and calcite grains.

Heavy mineral analyses were carried out for two xenoliths from the porphyritic phase, one dark brown with abundant biotite and the other light grey and containing little biotite. The presence of occasional rounded zircons in each suggests that most of the xenoliths represent granitized sediments.

The development of hornblende at the expense of biotite in several of the xenoliths from the non-porphyritic phase, and the apparent lack of orthoclase in several of these xenoliths suggest that the magma of the outer base was slightly undersaturated with respect to K_2O, as concluded for the Morang Granodiorite by Edwards and Baker. However, it is likely that the gabbroic xenolith (Section 8540) is a metamorphosed basic igneous rock, as the manner in which the augite porphyroblasts enclose labradorite is reminiscent of ophitic texture.

Dykes and Veins:

Thin aplites and pegmatites occur occasionally in both phases of the granodiorite, but together with quartz veins, are numerous in a small quarry at Nimmo Falls, Wallaby Ck Reserve. The micropegmatites and aplites show typical saccharoidal texture, being grey to cream in colour, with occasional dark flecks of tourmaline. Sections 8547 and 8548 consist chiefly of quartz and cloudy orthoclase often in granophyric intergrowth, with lesser amount of oligoclase and albite. Muscovite laths are generally arranged in radial clusters; biotite is rare. The tourmaline is interstitial, consisting mainly of brown schlorite, with a little blue elabite. Accessory minerals include pyrite grains and small zircons.

Thin quartz veins ¼ to ½ in. wide are common throughout the Kinglake district, comb structure and vuggy spaces suggesting injection under tension; occasional slickensided quartz along bedding planes and veins displaced by small faults indicate slight post-injection tectonic activity.

Structural Features:

Contacts.

The only places where the actual contact between granodiorite and country-rock is exposed are two cuttings on the NW. boundary, where it is roughly vertical. The relatively narrow metamorphic aureole suggests that this is so for most of the massif, although the greater width of the aureole along the arcuate NE. boundary may be due to the contact here dipping to the E.

The combination of arcuate and linear trends of the contact is a notable feature of the massif. The straight SE. boundary, about 6 miles long, almost certainly represents a large pre-intrusion fault, and the arcuate NE. contact is similar to the ring fracturing associated with numerous other Central Victorian granitic intrusions (Hills 1959). The linear portions of the NW. contact also suggest pre-intrusion faulting.